Agenda Item: 8.

Memorandum

To: Programs, Projects and Operations Subcommittee
From: Amanda Grint, Water Resources Engineer
Date: June 2, 2014
Re: Contract Proposal with USGS for Flood Inundation Mapping on the Big Papillion Creek

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The US Army Corps of Engineers and the District have been working for a number of years on an updated flood study for the Big and Little Papillion Creek systems. An outcome of this study will be new Federal Emergency Management Agency (FEMA) Digital Flood Insurance Rate Maps (DFIRMs). The updated DFIRMs will show 100 year, or 1% annual chance, flood inundation which is the flood insurance regulated storm event.

Although information is available for individuals to readily see the 100-year or 1% annual chance inundation area on the FEMA DFIRMs, there is no way to show what inundation areas look like for various storms that correspond to the forecasted water-level stages. The District administers a floodwarning system along with the USGS, National Weather Service and local partners to provide real time water-level stages in the Papillion Creek Watershed.

The proposal from the USGS is to create a flood inundation library for the Big Papillion Creek (from Fort Street to several miles downstream of Q Street) that will link the real time water level stages with inundation mapping and flood depths. See attached fact sheet from the USGS on flood inundation mapping. This type of data provide the communities, emergency responders and the public with valuable information on flood risk for storms outside the boundaries of the FEMA DFIRMs.

The proposal from the USGS would be completed mostly within the District's FY15 with the website posting taking place in FY16. The proposed cost for the flood inundation mapping is $65,100 and the District portion of the cost share would be $35,100 with the USGS contributing $30,000.

Management recommends that the Subcommittee recommend to the Board that the General Manager be authorized to execute a proposed contract with the USGS in the amount of $65,100 for Flood Inundation Mapping for the Big Papillion Creek from Fort Street to downstream of Q Street subject to changes deemed necessary by the General Manager and approval as to form by District Legal Counsel.

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USGS Flood Inundation Mapping Program: Communicating Flood Risk and Consequences to Communities

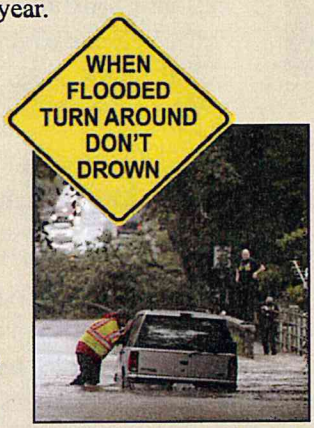
Flooding is a national problem…

Over the past 30 years, annual flood losses averaged about $7.82 billion with 94 fatalities per year.

2011 FLOOD FACTS:

- $8.26 billion in direct damages
- 113 reported fatalities
  - 63% related to driving on flooded roadways
  - 15% related to falling into floodwaters
  - 62% of the victims were male

Source: http://www.nws.noaa.gov/hic/flood_safety/index.shtml



Atlanta, GA

…but part of the solution is local

The **USGS Flood Inundation Mapping Program** focuses its efforts at state and local levels to help communities understand flood risks and make cost-effective mitigation decisions. We partner with local communities to assist in the development and validation of flood inundation map libraries. Communities use these maps to help protect lives and property.

The USGS works with the National Weather Service, the U.S. Army Corps of Engineers, and the Federal Emergency Management Agency to connect communities with available federal resources thereby ensuring the quality and consistency of flood inundation maps across the country.

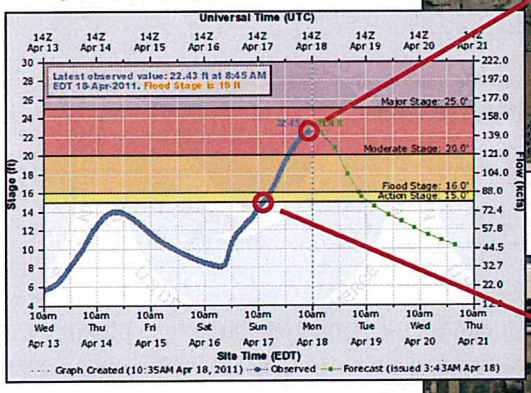
What is a flood inundation map library?

A **flood inundation map library** contains a series of sequential maps that help communicate where flooding may occur over a range of river levels. The library can be connected to real-time and forecasted river levels at USGS streamgages to help communities identify immediate risks during a flood.

INUNDATION MAPS CAN BE USED FOR:

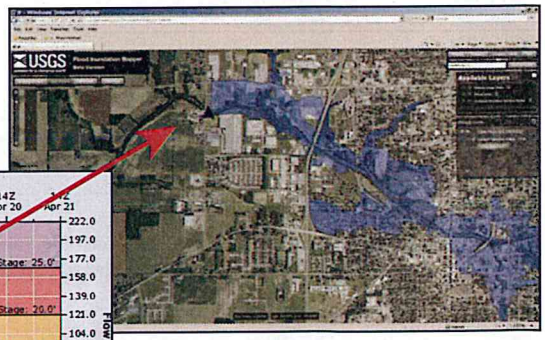
- **Preparedness** - "What-if" scenarios
- **Timely Response** - tied to real-time gage and forecast information
- **Recovery** - damage assessment
- **Mitigation and Planning** - flood risk analyses
- **Environmental and Ecological Assessments** - wetlands identification, hazardous spill cleanup

Example hydrograph of a flood:



Inundation maps translate flood data into operational maps that communicate risk and the consequences of current and forecasted flooding.

High flood stage inundation map:



Low flood stage inundation map:

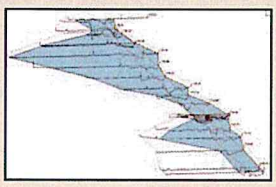
How do we make a Flood Inundation Map Library?

Step 1 - Stream selection

The mapping process is initiated by a local community that is interested in identifying its flood risk. The most appropriate stream or river reaches are near USGS streamgages located in a populated areas. The National Weather Service (NWS) produces flood forecasts at about half of USGS-gaged streams. These stream reaches are preferred because they support both flood monitoring and response activities.

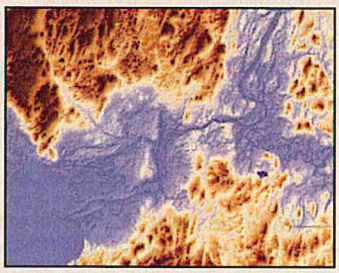
Step 2 - Hydraulic modeling

A carefully calibrated hydraulic model is developed for the selected stream reach and is used to define the height of a flood along the reach at a selected river level. This model is run multiple times for sequential levels, producing a series of flood heights from near-bankfull river levels to record flooding levels.



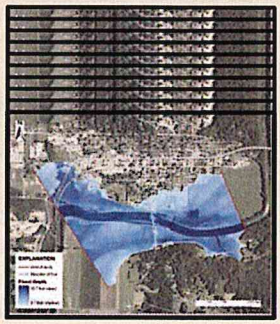
Step 3 - Geospatial processing

The hydraulic model results are intersected with a very detailed (LiDAR-based) ground-surface elevation model (DEM). This process creates a spatial grid showing the depth of flooding at each cell in the modeled flood area. These grids define the probable areas of floodwater inundation.

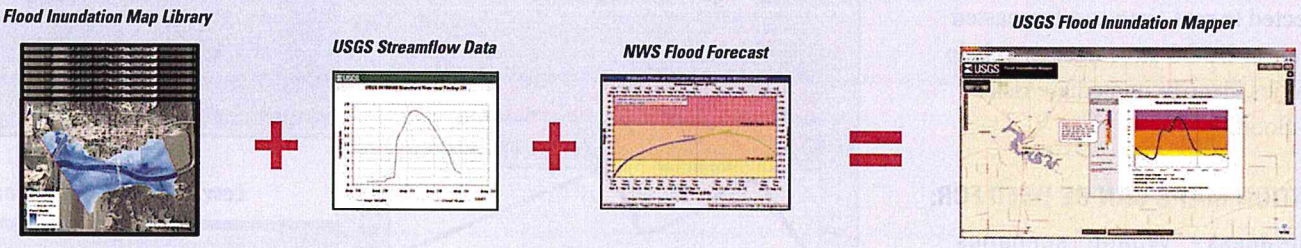


Step 4 - Map library production

A **flood inundation map** shows the probable areas of floodwater inundation overlaid onto a city map, which help communities plan and respond to floods. A **flood inundation map library** is the full set of maps showing flood inundation from near-bankfull river levels to record flooding levels.



Bring it all together using the online Flood Inundation Mapper...



The **USGS Flood Inundation Mapper** combines the flood inundation map libraries with real-time USGS river-level data and National Weather Service flood forecasts into a powerful tool that helps communicate when and where it may flood and allows for better tools to inform local responses that can protect lives and property.

Access the Flood Inundation Mapper and available flood inundation map libraries at: ***http://water.usgs.gov/osw/flood_inundation***

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For assistance with developing a flood library for your community, please contact your local USGS office: ***www.usgs.gov***

FLOOD INUNDATION MAPPING FOR BIG PAPILLION CREEK IN OMAHA, NEBRASKA

PAPIO-MISSOURI NATURAL RESOURCES DISTRICT

By
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U.S. Geological Survey
Nebraska Water Science Center
Lincoln, Nebraska

May 19, 2014

BACKGROUND AND PROBLEM

The Papillion Creek watershed is one of the most flood-prone areas in the State of Nebraska. It is also one of the most heavily populated. Development and urbanization of the western part of the watershed causes a dramatic increase in the amount of stormwater runoff. This, in turn, increases the severity and occurrence of flooding. (Papio-Missouri River Natural Resources District, undated)

The U.S. Army Corp of Engineers (USACE), in conjunction with the Papio-Missouri River Natural Resources District (NRD), is in the process of completing the hydrologic and hydraulic analyses and mapping of the Papillion Creek watershed and drafting Digital Flood Insurance Rate Maps (DFIRMs). Although DFIRMs allow users to see which areas could be affected by floods with a 1% and 0.2% chance of being equaled or exceeded in any given year, they do not show the extent and depth of flood inundation that could occur based on forecasted water-level stage during a flooding event. To address this information gap, the United States Geological Survey (USGS) has developed the Flood Inundation Mapping Program (U.S. Geological Survey, 2012), so that the extent and depth of flooding based on forecasted or actual water-level stage can be displayed in real time at the USGS Flood Inundation Mapper (FIM) Web site (http://wim.usgs.gov/FIMI/FloodInundationMapper.html#). This would provide valuable flood-inundation maps and data to emergency responders, floodplain managers, the media, and the public—available via the Internet—on a continuous and real-time basis.

OBJECTIVES AND SCOPE

The objective of this proposal is to create a flood-inundation-map library for the Big Papillion Creek (fig. 1) that will be linked to real-time water-level stage information at existing USGS stream-gaging locations and display estimated flood-inundation areas and flood depths. These maps will be served to the public on the USGS FIM Web site: http://wim.usgs.gov/FIMI/FloodInundationMapper.html#. The maps will be created for the reach of the Big Papillion Creek from several miles upstream of the USGS stream gage Big Papillion Creek at Fort Street at Omaha, Nebr. (station number 06610732), to several miles downstream of the USGS stream gage Big Papillion Creek at Q Street at Omaha, Nebr. (station number 06610770). Flood-inundations maps will be created at one-foot intervals for stages from approximately bankfull to the maximum observed stage at the stream gage. If requested by the NRD, the USGS will extend the inundation maps above the stage of the maximum observed stage.

RELEVANCE AND BENEFITS

The proposed work is consistent with the USGS's Strategic Direction, Facing Tomorrow's Challenges—U.S. Geological Survey Science in the Decade 2007-2017 (Circular 1309). This issue specifies that the USGS conduct studies to understand areas at risk from natural hazards and provide information to safeguard people and property. Flood-inundation-map libraries provide the NRD, city, and floodplain managers, emergency responders crews, and the public with a valuable tool to protect life and property. Flood-inundation mapping converts a point measurement of stage-discharge at a stream gage and expands it to an aerial map that communicates the flood risk to a wide area. The maps will provide city and emergency responders with information to better coordinate in times of flooding (anticipation of road closures, evacuation of areas, etc.) to better protect life and property. The maps also provide the community a flood-risk awareness and education tool to better inform the public of flood risks that exist outside of the traditional DFIRMs. Finally, the maps will provide the NRD and city a tool to help in future flood planning and risk mitigation.

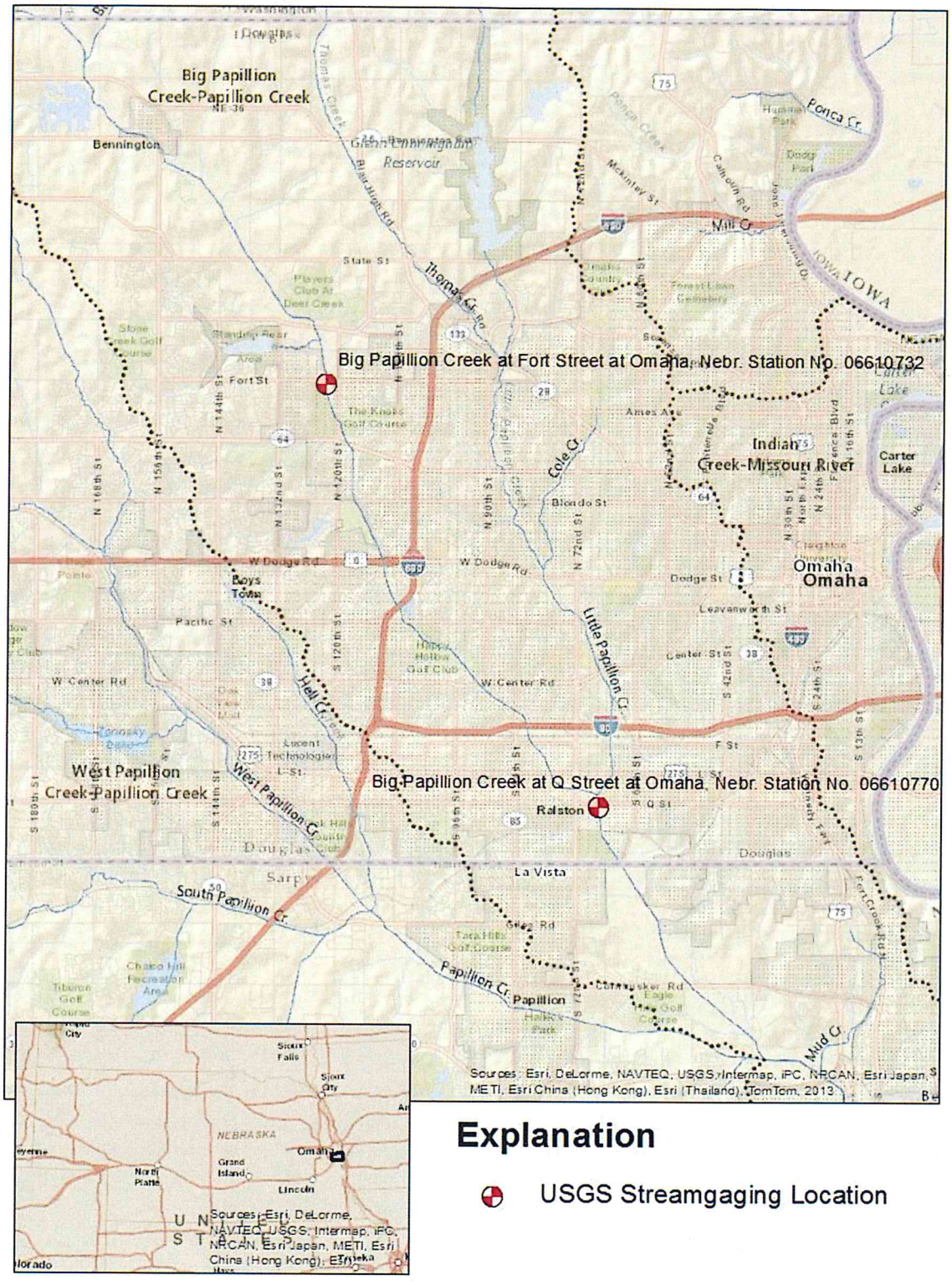

Figure 1. Big Papillion Creek study area

APPROACH

The USGS is proposing to develop flood-inundation-map libraries for a range of flood stages ranging from approximately bankfull to the maximum observed stage at the stream gage in one-foot increments. If requested by the NRD, the USGS will extend the inundation maps above the stage of the maximum observed stage. The flood-map library will be posted to the USGS FIM Web site (fig. 2), which displays extent and depth of flooding based on actual water-level stage in real time. The USGS will perform the work in 5 steps: 1) compile necessary data, 2) hydraulic modeling, 3) flood-layer development, 4) posting to the FIM Web site, and 5) documentation. The steps are described in more detail below.

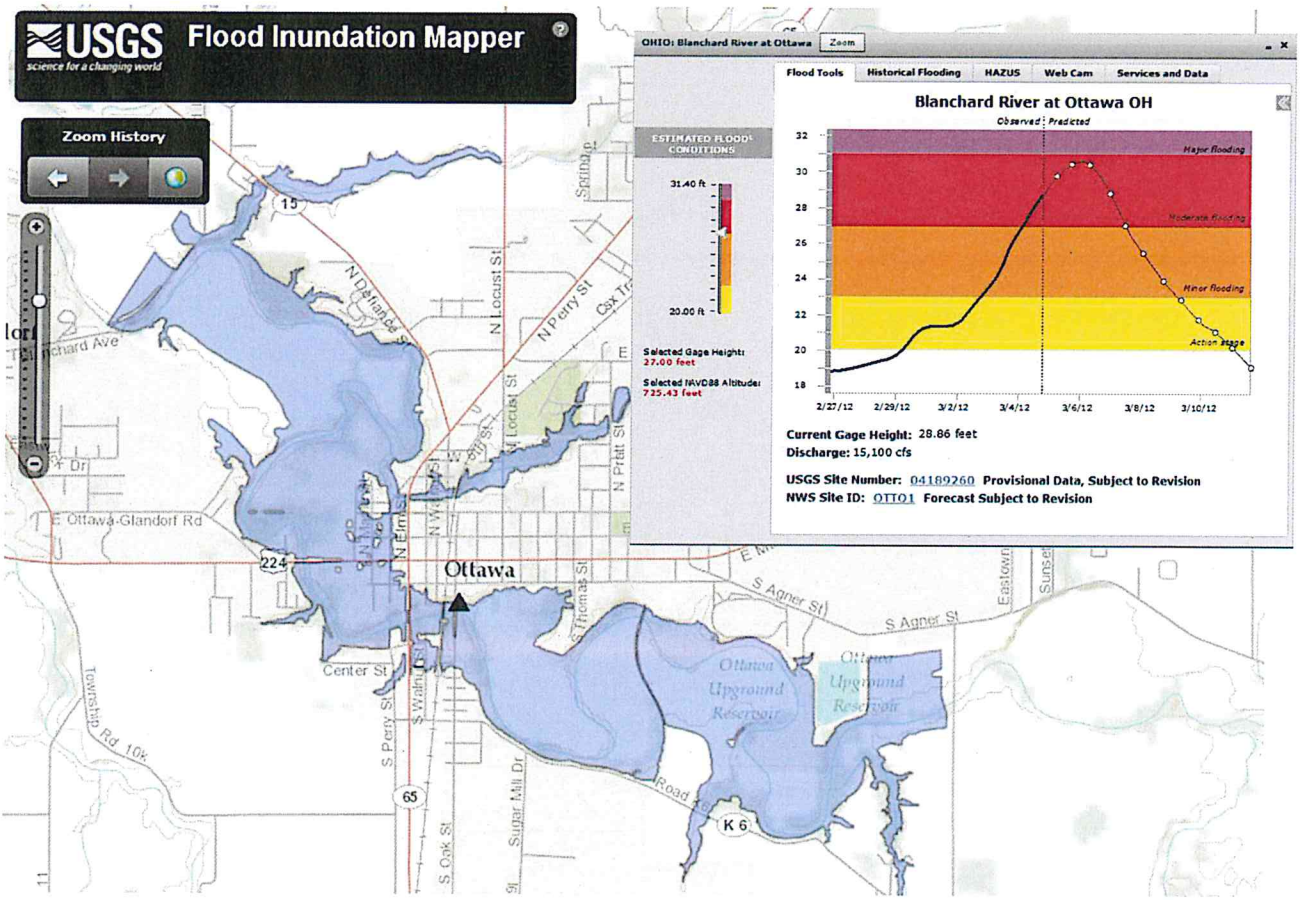

Figure 2. Example displaying flood inundation maps on the FIM Web site.

1. Data Compilation. Hydrographic and topographic datasets needed for the project will have vertical datum of North American Vertical Datum of 1988 (NAVD 88) and a horizontal datum of North American Datum of 1983 (NAD 83). VERTCON software will be used to convert datasets of other datums to NAVD 88. LiDAR collected by the Nebraska Iowa Regional Orthophotography Consortium in 2010 will be used for the elevation base source for model development and flood-map creation. Hydrographic datasets will consist of stream-gage datum elevation, historic flood-peak information, stream-gage rating curve, high-water mark data, historic flood profiles, FEMA flood insurance study (FIS) materials, and existing hydraulic and hydrologic models developed by the USACE.

2. Hydraulic Modeling. Water-surface profiles for the flood-inundation-map library will be created using a hydraulic stream model. For this study it will be valid to assume steady-state conditions. HEC-RAS

models developed by the USACE will be used to model the reach. Streamflow will be obtained from the most current rating curve from the collocated stream gage. The downstream water-surface elevation will be determined by high-water-mark data, historic profile data, and/or specifying an energy slope that will be used to determine normal depth. The USGS will calibrate the models to water-level stage data at the USGS Big Papillion Creek at Fort Street stream gage (station number 06610732) and USGS Big Papillion Creek at Q Street stream gage (station number 06610770), as well as other available flood peak information for the reach. Manning's N roughness coefficient and other hydrologic parameters will be adjusted as needed.

3. Flood-Layer Development. The water-surface profiles developed by the hydraulic modeling for each stage will be used to create a series of water-surface GRIDS (ESRI raster format). Using GIS the ground-surface DEM will be subtracted from the water-surface GRID, the resulting layer will be a depth GRID with the positive values indicating flooded areas. The resulting inundation depth GRID (positive values only) will then be exported as a polygon layer, and polygons not connected to the main reach will be deleted. This process will be repeated for each modeled stage.

4. Posting to the USGS Flood Inundation Mapper. Each provisional map library, hydraulic models, and supporting documentation will be reviewed by a team consisting of the following: two USGS technical reviewers and NRD personnel. Once approved the maps will be made available to the public on the USGS FIM Web site: http://wim.usgs.gov/FIMI/FloodInundationMapper.html#.

5. Documentation. The USGS will document steps necessary to produce the maps in an online Scientific Investigations Report (SIR). GIS layers will be documented with the appropriate metadata. The report and metadata will be written, reviewed, and published according to USGS publications approval standards.

PRODUCTS

The product of the study is an online USGS SIR and GIS inundation area polygon layers and depth GRIDS, as well as posting of the map library to the FIM Web site.

SCHEDULE

Proposed study will span the federal fiscal years 2014-2015.

Activity	2014		2015			
	Q3	Q4	Q1	Q2	Q3	Q4
1. Data Compilation	X	X				
2. Hydraulic Modeling		X	X	X		
3. Flood Layer Development				X	X	
4. FIM website posting and 5. Documentation					X	X

PROJECT COST (FEDERAL FISCAL YEAR 2014-2015)

Papio-Missiouri NRD	$35,100
USGS	$30,000
Total	$65,100

REFERENCES

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Strauch, K.R., 2013, Flood-inundation maps for the Elkhart River at Goshen, Indiana: U.S. Geological Survey Scientific Investigations Map 3269, 9 sheets, 7-p. pamphlet, http://dx.doi.org/10.3133/sim3269.

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Zarriello, P.J., Olson, S.A., Flynn, R.H., Strauch, K.R., and Murphy, E.A., 2014, Simulated and observed 2010 floodwater elevations in selected river reaches in the Pawtuxet River Basin, Rhode Island: U.S. Geological Survey Scientific Investigations Report 2013–5192, 49 p., http://dx.doi.org/10.3133/sir20135192.

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

Flood-Inundation Maps for the Elkhart River at Goshen, Indiana

Pamphlet to accompany

Scientific Investigations Map 3269

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

Cover. Simulated floods corresponding to a stage of 5.0, 9.0, and 13.0 feet at U.S. Geological Survey streamgage 04100500 on the Elkhart River and image of the Elkhart River downstream from the streamgage. Photograph by Edward Dobrowolski, U.S. Geological Survey.

Flood-Inundation Maps for the Elkhart River at Goshen, Indiana

By Kellan R. Strauch

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

Pamphlet to accompany

Scientific Investigations Map 3269

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: 2013

Suggested citation:
Strauch, K.R., 2013, Flood-inundation maps for the Elkhart River at Goshen, Indiana: U.S. Geological Survey Scientific Investigations Map 3269, 9 sheets, 7-p. pamphlet, *http://dx.doi.org/10.3133/sim3269*.

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The author wishes 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 Transportation. Special thanks are given to the City of Goshen and Elkhart County staff for their cooperation in this study by providing data and reviewing flood-inundation maps prior to publication, and to the National Weather Service for their continued support of the U.S. Geological Survey flood-inundation mapping initiative.

Contents

Sheets

[Sheets and additional materials are available online at *http://pubs.usgs.gov/sim/3269/*]

Figures

Tables

Conversion Factors

Inch/Pound to SI

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 foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer [$(m^3/s)/km^2$]
	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).

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

Flood-Inundation Maps for the Elkhart River at Goshen, Indiana

By Kellan R. Strauch

Abstract

The U.S. Geological Survey (USGS), in cooperation with the Indiana Office of Community and Rural Affairs, created digital flood-inundation maps for an 8.3-mile reach of the Elkhart River at Goshen, Indiana, extending from downstream of the Goshen Dam to downstream from County Road 17. 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 nine selected water levels (stages) at the USGS streamgage at Elkhart River at Goshen (station number 04100500). Current conditions for the USGS streamgages in Indiana may be obtained on the Internet at *http://waterdata.usgs.gov/*. In addition, stream-stage data have been provided to the National Weather Service (NWS) for incorporation into their Advanced Hydrologic Prediction Service (AHPS) flood-warning system (*http://water.weather.gov/ahps/*). The NWS forecasts flood hydrographs at many places that are often collocated with USGS streamgages. NWS-forecasted peak-stage information may be used in conjunction with the maps developed in this study to show predicted areas of flood inundation.

In this study, flood profiles were computed for the stream reach by means of a one-dimensional step-backwater model. The model was calibrated using the most current stage-discharge relation at the Elkhart River at Goshen streamgage. The hydraulic model was then used to compute nine water-surface profiles for flood stages at 1-foot (ft) intervals referenced to the streamgage datum and ranging from approximately bankfull (5 ft) to greater than the highest recorded water level (13 ft). 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) data having a 0.37-ft vertical accuracy and 3.9-ft horizontal resolution in order to delineate the area flooded at each water level. The availability of these maps, along with Internet information regarding current stage from USGS streamgages and forecasted stream stages from the NWS, provide emergency management personnel and residents with information that is critical for flood response activities such as evacuations and road closures as well as for postflood recovery efforts.

Introduction

The City of Goshen in Elkhart County, Indiana (Ind.), an urban community with a reported population of 31,719, is part of the Elkhart-Goshen Metro Area (pop. 197,561 in 2010; U.S. Census Bureau, 2010). Peak streamflows, since 1925, and continuous stage measurements, since 1931, have been recorded at a U.S. Geological Survey (USGS) streamgage on the Elkhart River at Goshen (station number 04100500). The peak discharge of record, 6,360 cubic feet per second (ft^3/s) at a stage of 11.87 feet (ft; gage datum), occurred on February 24, 1985. The most recent flood event with approved flow data (stage above 7 ft) occurred April 29, 2011, with a flow of 3,450 ft^3/s and a stage of 7.99 ft. Flood plains within Goshen are moderately developed and contain a mix of residential and commercial structures.

Prior to this study, Goshen 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 Elkhart County, which includes the City of Goshen and is dated August 2, 2011 (Federal Emergency Management Agency, 2011). A second source of information is the USGS streamgage, Elkhart River at Goshen (station number 04100500), from which current or historical water levels (stages) can be obtained. A third source is the National Weather Service's (NWS) Advanced Hydrologic Prediction Service (AHPS), which also displays current stage data from the USGS gage, as well as river forecasts of stage during times of high water. Although USGS current stage and NWS forecast stage information is particularly useful for residents in the immediate vicinity of a streamgage, it is of limited use to residents farther upstream or downstream because the water-surface elevation is not constant along the entire stream

channel. Also, FEMA and State emergency management mitigation teams or property owners typically lack information related to how deep the water is at locations other than near USGS streamgages or NWS flood-forecast points. In 2011–12, the USGS, in cooperation with the Indiana Office of Community and Rural Affairs, conducted a study to produce a library of flood-inundation maps for an 8.3-mile (mi) reach of the Elkhart River at Goshen. The inundation maps depict estimates of the areal extent and depth of flooding corresponding to selected water levels (stages) at the USGS streamgage, Elkhart River at Goshen (station number 04100500).

Purpose and Scope

The purpose of this report is to describe the development of a series of maps showing the estimated flood-inundation extent for the Elkhart River at Goshen, Ind. The maps are accessed through the USGS Flood Inundation Mapping Science Web site at *http://water.usgs.gov/osw/flood_inundation/* and the NWS AHPS Web site at *http://water.weather.gov/ahps/*. Internet users can select estimated inundation maps that correspond to (1) current stage at the USGS streamgage, (2) the NWS-forecasted peak stage, or (3) other stream stages of interest.

The scope of the study was limited to the Elkhart River from downstream of Goshen Dam to a point 5,450 ft downstream from the County Road 17 bridge (fig. 1). Tasks specific to development of the maps were:

1. collection of topographic and bathymetric data for selected cross sections and geometric data bridges along the study reach,
2. estimation of energy-loss factors (roughness coefficients) in the stream channel and flood plain, and determination of steady-flow data,
3. computation of water-surface profiles using the U.S. Army Corps of Engineers (USACE) HEC–RAS computer program (U.S. Army Corps of Engineers, 2010),
4. production of estimated flood-inundation maps at various stream stages using the USACE's 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 were generally cited from previously published reports. If techniques varied significantly from previously documented methods because of local hydrologic conditions or available data, they are described in detail in this report. Maps were produced for water levels referenced to the Elkhart River stage at the Goshen streamgage, which ranged from approximately bankfull (5 ft above gage datum) to greater than the maximum observed water level (13 ft) at the streamgage.

Study Area Description

The study reach of the Elkhart River is in Elkhart County in north-central Indiana. The drainage area ranges from 584 square miles (mi^2) at the outlet of Goshen Dam Pond to 643 mi^2 at the downstream extent of the study reach. The drainage area at the Elkhart River at Goshen streamgage is 594 mi^2. The stream's headwaters originate in Noble County, Ind., and the stream flows generally to the northwest before entering the city limits. One major tributary to the Elkhart River, Rock Run Creek (drainage area 42 mi^2), joins the main stem as it flows through Goshen. The basin terrain is generally flat. The study reach is approximately 8.3 mi long and has an average top-of-bank channel width of 186 ft and an average channel slope of 2.38 feet per mile (ft/mi) or 0.00045. About 49 percent of the land contiguous to the study reach is classified as urban or developed, 7 percent as forest, and 4 percent as cropland (Homer and others, 2007). The study area is still undergoing development, and the population has increased 8 percent from 29,383 to 31,719 between 2000 and 2010 (U.S. Bureau of Census, 2010). The main channel within the study reach is bridged by six major roads and a railroad.

Previous Studies

Although the current countywide FIS became effective in 2011 (Federal Emergency Management Agency, 2011), the data contained therein that deals with flooding in the City of Goshen is from the original FIS completed by Clyde E. Williams and Associates in 1977 (Federal Emergency Management Agency, 2011). That study provided information on the 10-, 2-, 1- and 0.2-percent annual exceedance probability water-surface profiles and associated 1- and 0.2-percent flood-plain maps for the Elkhart River and Rock Run Creek. The water-surface profiles and the flood frequencies on which they were based have not been updated since 1977; however, the flood-plain maps in the 2011 FIS do include revised flood-inundation delineations that were based on updated, detailed land-surface elevation data made possible by the use of Light Detection and Ranging (LiDAR).

Constructing Water-Surface Profiles

The water-surface profiles used to produce the nine flood-inundation maps in this study were computed using HEC–RAS, version 4.1.0 (U.S. Army Corps of Engineers, 2010). HEC–RAS is a one-dimensional step-backwater model

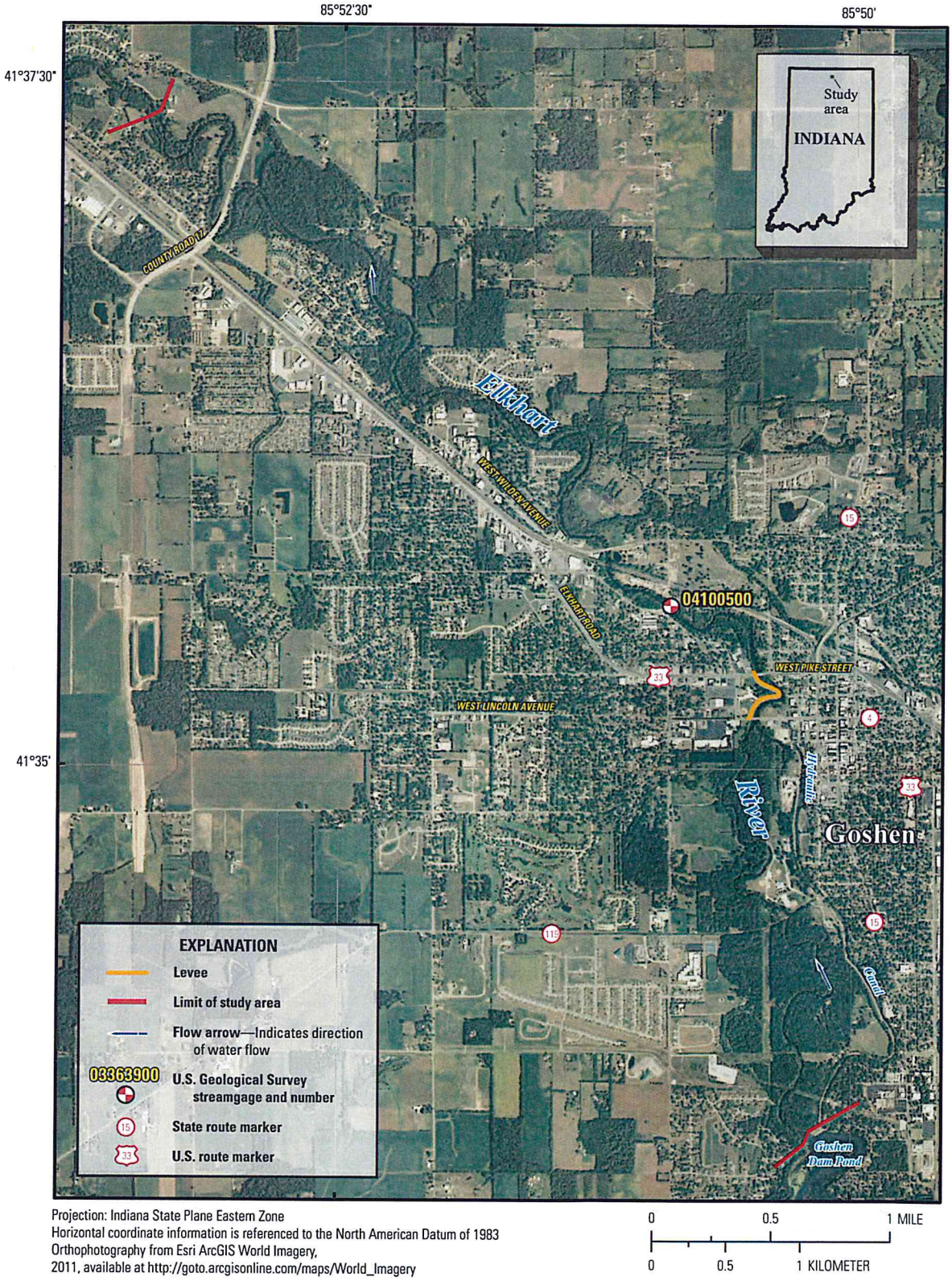

Figure 1. Location of study reach for the Elkhart River, U.S. Geological Survey streamgage, and National Weather Service forecast site.

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 done using the steady-state flow computation option.

Hydrologic and Steady-Flow Data

The study area hydrologic network consists of one streamgage (04100500; fig. 1; table 1). Water level (stage) is measured continuously at the site, and the continuous record of streamflow is computed for the site. All water-surface elevations reported herein are referenced to the North American Vertical Datum of 1988 (NAVD 88). The gage is equipped with a satellite radio transmitter that allows these data to be transmitted routinely for posting on the Internet within an hour of collection.

Steady-flow data consisted of flow regime, boundary condition set to normal depth, and peak-discharge information. Because there are no major tributaries from the upstream limit of the study area to the Elkhart River at Goshen streamgage, flow data for the upstream end of the study reach were obtained from the current stage-to-discharge relation, which has been developed from measurements of streamflow at the Elkhart River at Goshen streamgage. For the downstream part of the study reach, discharge recorded at the streamgage was increased proportional to the drainage-area ratio to account for the expected increase in flows from Rock Run Creek, a tributary that enters the study reach about 403 ft downstream from the West Wilden Avenue bridge. These adjusted flow values were used in the model from the confluence of Rock Run Creek and Elkhart River to the downstream limit of the study reach.

Topographic and Bathymetric Data

Channel cross sections were surveyed by USGS personnel during April 2012 for locations. These cross sections provided detailed channel-elevation data below the water surface and 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 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 LiDAR-derived digital elevation model (DEM). The LiDAR data were collected during April 2010 by AeroMetric, Inc., Sheboygan, Wisconsin, and postprocessing of these data also was completed by AeroMetric, Inc. The original LiDAR data have horizontal accuracy of 1.02 ft (31 centimeters), horizontal resolution of 3.9 ft (1.2 meters), and vertical accuracy of 0.37 ft at a 95-percent confidence level for the "open terrain" land-cover category (root mean squared error of 0.19 ft [5.8 centimeters]). Although a finer horizontal resolution of the DEM was possible given the accuracy of the LiDAR data, the final DEM was resampled to a grid-cell size of 10 square feet (ft^2) to decrease GIS processing time.

Seven bridges and roadway embankments, and one levee, 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, structural dimensions for three bridges (West Plymouth Avenue, River Avenue, and West Wilden Avenue) were measured and surveyed in the field concurrently with the stream-channel surveys. Dimensions for West Lincoln Avenue, West Pike Street, and the railroad bridges were obtained from input data for a HEC–2 hydraulic model, which was developed in 1977 and is still the basis for the water-surface profiles and flood maps that are presented in the currently effective FIS (Federal Emergency Management Agency, 2011). Structural dimensions for the County Road 17 bridge were obtained from design plans provided by the Elkhart County Highway Department (Thomas Rushlow, Elkhart County Highway Department, written commun., June 2012). A detailed description of the methods used to acquire and process the topographic and bathymetric data can be found in Bales and others (2007). The Roger's Park Levee runs longitudinally next to the stream between West Lincoln Avenue and West Pike Street. The levee protects the Roger's Park area from flood waters for water-surface elevations below 776.03 ft NAVD 88, but at water-surface elevations above 776.03 feet the levee is overtopped and the area behind it is inundated with flood waters.

Energy-Loss Factors

Field observations and high-resolution aerial photographs were used to select initial (precalibration) Manning's roughness coefficients ("*n*" values) for energy (friction) -loss

Table 1. U.S. Geological Survey streamgage site information for the study area, Elkhart River at Goshen, Indiana.

[mi^2, square miles; ft, feet; NAVD, North American Vertical Datum of 1988; °, degree; ′, minutes; ″, seconds]

Station name	Station number	Drainage area (mi^2)	Latitude	Longitude	Period of record	Maximum recorded flood elevation at gage and date
Elkhart River at Goshen, Indiana	04100500	594	41°35′36″	85°50′55″	Oct. 1931 to current year	11.94 Mar. 14, 1982

calculations. The final Manning's *n* values used ranged from 0.040 to 0.052 for the main channel and 0.088 to 0.165 for the overbank areas modeled in this analysis.

Model Calibration and Performance

The hydraulic model was calibrated to the most current stage-discharge relation at the USGS streamgage 04100500, Elkhart River at Goshen, Ind. Model calibration was accomplished by adjusting Manning's *n* values until the results of the hydraulic computations closely agreed with the measured flood discharge and stage values. Differences between measured and simulated water levels for measured or rated flows at USGS gaging station 04100500 were equal to or less than 0.02 ft (table 2). Details on techniques used in model development and calibration can be found in Bales and others (2007).

Table 2. Comparison of hydraulic-model output simulated and observed water-surface elevations at the Elkhart River at Goshen, Indiana, streamgage (station number 04100500).

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

Stage (ft)[1]	Measured water-surface elevation (ft, NAVD 88)[1]	Modeled water-surface elevation (ft, NAVD 88)	Elevation difference (ft)
5.0	774.03	774.01	0.02
6.0	775.03	775.03	0.00
7.0	776.03	776.04	-0.01
8.0	777.03	777.04	-0.01
9.0	778.03	778.02	0.01
10.0	779.03	779.04	-0.01
11.0	780.03	780.04	-0.01
12.0	781.03	781.04	-0.01
13.0	782.03	782.03	0.00

[1]Values derived from rating curve no. 20 at U.S. Geological Survey gaging station 04100500.

Development of Water-Surface Profiles

Water-surface profiles were developed for a total of nine discharges corresponding to flood stages at 1-ft intervals between 5 and 13 ft above the gage datum (that is, water-level elevations ranging from 774.03 to 782.03 ft, NAVD 88), as referenced to the USGS streamgage 04100500, Elkhart River at Goshen, Ind. Discharges corresponding to the various index stages were obtained from the most current stage-discharge relation (no. 20.0) for the streamgage and were applied to the upstream half of the modeled reach, that is, from Goshen Dam to the confluence of Rock Run Creek with Elkhart River. For the downstream part of the study reach, discharge recorded at the streamgage was increased proportional to the drainage-area ratio to account for the expected increase in flows from Rock Run Creek. The assumption inherent in this calculation is that runoff in the Elkhart River Basin is distributed uniformly in time and space, and that the unit-area runoff, in cubic feet per second per square mile ($(ft^3/s)/mi^2$), in the Rock Run Creek Basin is equal to that in the Elkhart River Basin upstream from the streamgage at Goshen. Discharges for the nine profiles based on the stage-discharge relation at the Goshen gage and the adjusted discharges that were applied for the reach downstream from Rock Run Creek, are listed in table 3. Drainage area for Rock Run Creek was calculated using a USGS web-based GIS application, called StreamStats, which was accessed at *http://water.usgs.gov/osw/streamstats/indiana.html*.

Table 3. Stages and water-surface elevations with corresponding discharge estimates at selected locations along the Elkhart River at Goshen, Indiana, for simulated water-surface profiles.

[mi^2, square miles; ft, feet; ft^3/s, cubic feet per second; stage, in feet above gage datum; values in parentheses are water-surface elevations, in feet above the North American Vertical Datum of 1988]

Location	Drainage area (mi^2)	Stage (ft)								
		5 (774.03)	6 (775.03)	7 (776.03)	8 (777.03)	9 (778.03)	10 (779.03)	11 (780.03)	12 (781.03)	13 (782.03)
		Discharge (ft^3/s)								
U.S. Geological Survey streamgage 04100500	594	1,460	2,080	2,750	3,450	4,130	4,810	5,500	6,220	7,000
Downstream from confluence with Rock Run Creek	630	1,549	2,206	2,917	3,659	4,380	5,102	5,834	6,597	7,425
Map sheet number		1	2	3	4	5	6	7	8	9

Inundation Mapping

Flood-inundation maps were created for the nine water-surface profiles simulated for the Elkhart River. The maps were created in a GIS by combining the water-surface profiles and DEM data. The DEM was derived from LiDAR data with 3.9-ft horizontal resolution and a vertical accuracy of 0.37 ft. Although a finer resolution of the DEM was possible given the accuracy of the LiDAR data, the final DEM had a grid-cell size of 10 ft^2 to decrease the GIS processing time. 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 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.

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

The flood-inundation maps and study documentation are available online at the USGS Publications Warehouse (*http://pubs.usgs.gov/sim/3269/*). Also, a Flood Inundation Mapping Science Web site has been established at *http://water.usgs.gov/osw/flood_inundation/* to provide a portal for USGS flood-inundation study information to the public. That Web portal has a link (*http://wim.usgs.gov/FIMI/FloodInundationMapper.html*) to interactive online map libraries that can be downloaded in several commonly used electronic file formats for GIS dataset viewers. At the map library site, each stream reach displayed contains further links to NWISWeb graphs of the current stage and streamflow at USGS streamgage 04100500, to which the inundation maps are referenced. A link also is provided to the NWS AHPS site (*http://water.weather.gov/ahps/*) so that the user can obtain applicable information on forecasted peak stage. The estimated flood-inundation maps are displayed in sufficient detail to note the extent of flooding with respect to individual structures so that preparations for flooding and decisions for emergency response can be performed efficiently. Roadways and bridges were closely reviewed and are shown as shaded (inundated and likely impassable) or not shaded (dry and passable) to facilitate emergency planning and use. However, buildings that are shaded do not reflect inundation but denote that bare earth surfaces in the vicinity of the buildings are inundated. When the simulated water depth (as indicated in the Web Mapping Application by holding the cursor over an inundated area) in the vicinity of a building of interest exceeds that building's height, the structure can be considered fully submerged.

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 USGS streamgage 04100500, Elkhart River at Goshen, Ind. Water-surface elevations along the stream reaches were estimated by steady-state hydraulic modeling, assuming unobstructed flow, and using streamflows and hydrologic conditions anticipated at the USGS streamgage. The hydraulic model reflects the land-cover characteristics and any bridge, dam, levee, or other hydraulic structures existing as of September 2011. Unique meteorological factors (timing and distribution of precipitation) may cause actual streamflows along the modeled reach to vary from those assumed during a flood, which may lead to deviations in the water-surface elevations and inundation boundaries shown. Additional areas may be flooded because of 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 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 forecast period (every 6 hours and 3 to 5 days out in many locations). In the case of Elkhart River at Goshen, forecasts are issued as needed during times of high water, but are not routinely available at the time of this report (2013). For more information on AHPS forecasts, please see: *http://water.weather.gov/ahps/pcpn_and_river_forecasting.pdf.*

Summary

The U.S. Geological Survey (USGS), in cooperation with the Indiana Office of Community and Rural Affairs, produced digital flood-inundation maps for an 8.3-mile reach of the Elkhart River at Goshen, Indiana, extending from downstream of the Goshen Dam to 5,450 feet (ft) downstream from the County Road 17 bridge. The inundation maps, which can be accessed at 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 04100500, Elkhart River at Goshen, Ind. The nine flood stages selected range from approximately bankfull (5 ft above gage datum) to greater than the maximum observed water level (13 ft) at the streamgage. Current conditions for the USGS streamgages in Indiana may be obtained on the Internet at *http://waterdata.usgs.gov/nwis/*. In addition, stream stage data have been provided to the National Weather Service (NWS) for incorporation into their Advanced Hydrologic Prediction Service (AHPS) flood warning system (*http://water.weather.gov/ahps/*). The NWS forecasts flood hydrographs at many places that are often collocated with USGS streamgages. NWS-forecasted peak-stage information may be used in conjunction with the maps developed in this study to show predicted areas of flood inundation.

In this study, nine flood profiles were computed for the stream reach by means of a one-dimensional step-backwater model. The model was calibrated using the most current stage-discharge relation at the Elkhart River at Goshen streamgage. The hydraulic model generated water-surface profiles for flood stages at 1-ft intervals referenced to the streamgage datum and ranging from approximately bankfull (5 ft, gage datum) to greater than the highest recorded water level. The simulated water-surface profiles were then combined with a geographic information system digital-elevation model (derived from Light Detection and Ranging (LiDAR) data having a 0.37-ft vertical and 3.9-ft horizontal resolution) in order to delineate the area flooded at each water level. The availability of these maps, along with Internet information regarding current stage from USGS streamgages and forecasted stream stages from the NWS, provide emergency management personnel and residents with information that is critical for flood response activities such as evacuations and road closures as well as for postflood recovery efforts.

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