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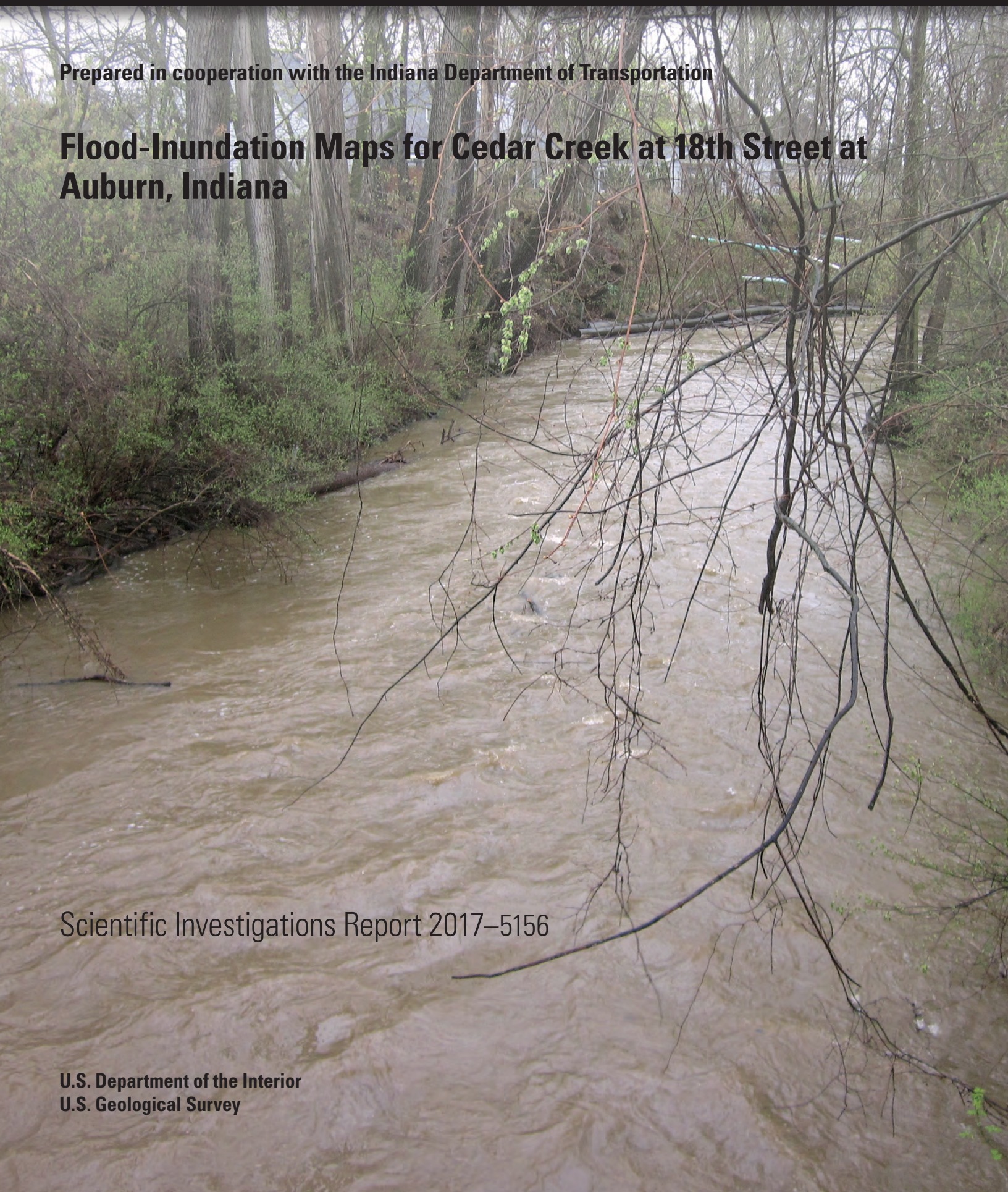
Flood-Inundation Maps for Cedar Creek at 18th Street at Auburn, Indiana



Scientific Investigations Report 2017–5156

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

Cover, front. Cedar Creek at 18th Street at Auburn, Indiana, Downstream Channel. April 20, 2015.

Cover, inside front. Cedar Creek at 18th Street at Auburn, Indiana, Downstream Channel with Acoustic Doppler Current Profiler (ADCP). February 24, 2014.

All photos taken by U.S. Geological Survey personnel.

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RYAN K. ZINKE, Secretary

U.S. Geological Survey
William H. Werkheiser, Deputy Director
exercising the authority of the Director

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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)
	Hydraulic gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)

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) or the National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Acknowledgments

The author wishes to thank the Maumee River Basin Commission for cooperating in the funding for the operation and maintenance of the streamgage used for this study. Special thanks are given to the Indiana Department of Transportation for their cooperation in this study and to the National Weather Service for their continued support to the U.S. Geological Survey flood-inundation mapping initiative.

Flood-Inundation Maps for Cedar Creek at 18th Street at Auburn, Indiana

By Kathleen K. Fowler

Abstract

Digital flood-inundation maps for a 1.9-mile reach of Cedar Creek at Auburn, Indiana (Ind.), from the First Street bridge, downstream to the streamgage at 18th Street, then ending approximately 1,100 feet (ft) downstream of the Baltimore and Ohio railroad, were created by the U.S. Geological Survey (USGS) in cooperation with the Indiana Department of Transportation. The flood-inundation maps, which can be accessed through the USGS Flood Inundation Mapping Science web site at https://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 on Cedar Creek at 18th Street at Auburn, Ind. (station number 04179520). Near-real-time stages at this streamgage may be obtained from the USGS National Water Information System at https://waterdata.usgs.gov/ or the National Weather Service Advanced Hydrologic Prediction Service at http://water.weather.gov/ahps/, although forecasts of flood hydrographs are not available at this site (ABBI3).

Flood profiles were computed for the stream reach by means of a one-dimensional step-backwater model. The hydraulic model was calibrated by using the most current stage-discharge relation at the Cedar Creek at 18th Street at Auburn, Ind. streamgage and the documented high-water marks from the flood of March 11, 2009. The calibrated hydraulic model was then used to compute seven water-surface profiles for flood stages referenced to the streamgage datum and ranging from 7 ft, or near bankfull, to 13 ft, in 1-foot increments. 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 0.98-ft vertical accuracy and 4.9-ft horizontal resolution) 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 at Cedar Creek at 18th Street at Auburn, Ind., and stream information from the National Weather Service, will 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 Auburn in DeKalb County, Indiana (Ind.), has an estimated population of 12,806 (U.S. Census Bureau, 2010). Auburn and the surrounding area have experienced flooding numerous times, most recently in 2008, 2009, 2012, and 2013. The majority of flood damages in the Auburn area have occurred along both overbanks of Cedar Creek (Federal Emergency Management Agency [FEMA], 2007). According to FEMA, most flooding occurs along Cedar Creek in Auburn as a result of runoff that is in excess of the existing channel capacity. The low areas of Eckhart Park and the county fairgrounds are the first to flood. As the stage increases, residential and commercial buildings are inundated, followed by agricultural areas (FEMA, 2006). Flood plains along the river are moderately developed and contain a mix of residential, commercial, and agricultural areas.

Prior to this study, emergency responders in Auburn relied on several information sources to make decisions on how to best alert the public and mitigate flood damages. One source is the FEMA flood insurance study (FIS) for DeKalb County (FEMA, 2006). A second source of information is the U.S. Geological Survey (USGS) streamgage, Cedar Creek at 18th Street at Auburn, Ind. (04179520), from which current (USGS, 2017c) and historical (USGS, 2017e) water levels (stage) and discharges can be obtained. A third source is the National Weather Service (NWS) web site for the streamgage, which displays stage at the USGS streamgage (NWS, 2017).

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, ease in visualizing the potential extent of flooding has been shown to motivate residents to take precautions and heed warnings that they previously might have disregarded. In 2016–17, the USGS, in cooperation with the Indiana Department of Transportation, conducted a project to produce a library of flood-inundation maps for Cedar Creek in Auburn, Ind.

Purpose and Scope

This report describes the development of a series of estimated flood-inundation maps for Cedar Creek at Auburn, Ind., and identifies where on the internet the maps can be accessed and ancillary data (geographic information system [GIS] flood polygons and depth grids) can be downloaded. Internet users can select estimated inundation maps that correspond to (1) flood stages at streamgage 04179520 and (2) the NWS site ABBI3. The scope of the study was limited to a 1.9-mile reach of Cedar Creek extending from the First Street bridge, downstream to the streamgage at 18th Street, and then ending 1,100 ft downstream of the Baltimore and Ohio railroad bridge (fig. 1).

The flood-inundation maps were produced for flood levels referenced to the stage recorded at streamgage 04179520 (table 1); the streamgage is on the west bank of Cedar Creek at the 18th Street bridge. The maps cover a range in stage from 7 to 13 feet (ft) in 1-ft increments. The 7-ft stage is just above bankfull stage. A stage of 13 ft is the highest stage of the stage-discharge rating number 1.2 (effective March 11, 2009). During a recent flood at Auburn on March 11, 2009, the stage was 12.3 ft, the highest recorded stage at this site (USGS, 2017d).

Study Area Description

Cedar Creek near the city of Auburn is in northeast Indiana near the center of the Auburn Morainal Complex physiographic section of the Northern Moraine and Lake Region (Gray, 2000). The drainage area is 87 square miles ($mi^{2)}$ at the upstream end of the study reach, 90.2 mi^2 at streamgage 04179520, and 90.7 mi^2 at the downstream end of the study reach (USGS, 2017c, 2017b). The headwaters originate in Dekalb County, Ind. at the outflow of Cedar Lake (not shown), and the stream flows generally southeastward and then swings back to the southwest as it flows through Auburn. Within the study reach, Cedar Creek has no significant tributaries.

Generally, the area is characterized by till ridges of moderate relief (Gray, 2000). The 1.9-mi study reach has an average top-of-bank channel width of about 62 ft and has an average channel slope of 0.0011 (5.7 feet per mile). Much of the land contiguous to the study reach north of Ensley Avenue is residential and commercial. The land south of Ensley Avenue is a combination of residential, commercial, and agricultural.

The population of Auburn has increased in recent years from 12,806 in 2010 to 13,052 in 2015 (U.S. Census Bureau, 2015). According to the U.S. Census Bureau, the city has a total area of 7.1 mi^2. The main channel and adjacent flood plain within the study reach have seven major road crossings with bridges at; First Street, Highway 8, Ninth Street, an abandoned railroad, 19th Street, Auburn Drive, and the Baltimore and Ohio railroad. There are two pedestrian walkways (park bridges), two utility service bridges, and a bridge to the fairgrounds.

Table 1. U.S. Geological Survey streamgage information for Cedar Creek at 18th Street at Auburn, Indiana (station number 04179520).

[Station location is shown in figure 1. mi^2, square miles; NAD 83, North American Datum of 1983; NGVD 29, National Geodetic Vertical Datum of 1929: NAVD 88, North American Vertical Datum of 1988; ft^3/s, cubic feet per second; °, degree; ‘, minutes; “, seconds; ft, feet]

Streamgage name	Streamgage number	Drainage area (mi^2)	Latitude (NAD 83)	Longitude (NAD 83)	Period of record	Datum of streamgage (NGVD 29)	Maximum recorded stage and date	Maximum discharge (ft^3/s) during period of record and date
Cedar Creek at 18th Street at Auburn, Indiana	04179520	90.2	41°21’36”	85°02’57”	September 2001 to present (2017)	844.02 ft	12.30 ft on March 11, 2009 (corresponds to an elevation of 855.84 (NAVD 88)[1])	2,290[2], March 11, 2009

[1]Datum of 843.54 (NAVD 88) was used to convert stage to water-surface elevation.

[2]Discharge based on U.S Geological Survey rating number 1.2.

Figure 1. Locations of the study reach for Cedar Creek at 18th Street at Auburn, Indiana; U.S. Geological Survey streamgage 04179520; and National Weather Service forecast site ABBI3.

Previous Studies

The most recent FIS that provides information for the study area including Cedar Creek at 18th Street at Auburn is the FIS for Dekalb County (FEMA, 2006). The FIS for Dekalb County covers the geographic area of Dekalb County, Ind., including the community of Auburn. The hydrologic and hydraulic analysis for the county study was performed by Fuller, Mossbarger, Scott, and May Engineers, Inc. for the Federal Insurance Administration under Task Order number EMC–2003–TO–013 and was completed in May of 2004.

FEMA has produced Digital Flood Insurance Rate Maps that include the study area in DeKalb County (FEMA, 2007). These maps outline the special flood-hazard areas in Dekalb County and the town of Auburn.

The Indiana Department of Natural Resources, the USGS, the Natural Resources Conservation Service, and the U.S. Army Corps of Engineers (USACE) have agreed upon discharges for annual exceedance probabilities for sites along many rivers in Indiana; the values are termed "coordinated discharges" and assure consistency among the State and Federal agencies that undertake streamflow studies (Indiana Department of Natural Resources, 2014). The coordinated discharges for Cedar Creek at 18th Street at Auburn were obtained from the USGS StreamStats Program for Indiana streams (USGS, 2017b) and are listed in table 2. These coordinated discharges are for the 10 and 1 percent annual exceedance probabilities.

From 1943 to 1973, the Cedar Creek at Auburn streamgage (04179500) was located at Ninth Street, 0.42 mi upstream of the current location. Peak stage at this location was 10.63 ft with a discharge of 2,100 cubic feet per second.

Table 2. Coordinated discharges for selected annual exceedance probabilities for Cedar Creek at 18th Street at Auburn, Indiana.

[mi^2, square miles; ft^3/s, cubic feet per second; USGS, U.S. Geological Survey]

Location	Drainage area (mi^2)	Coordinated discharges (ft^3/s)[1,2] for indicated annual exceedance probabilities (in percent)	
		10	1
At USGS streamgage number 04179520	90.2	1,490	2,110

[1]Data from The StreamStats Program (U.S. Geological Survey, 2017b).

[2]Data from Indiana Department of Natural Resources coordinated discharges for Cedar Creek at 18th Street at Auburn, Indiana.

Creation of Flood-Inundation Map Library

The USGS has standardized the procedures for creating flood-inundation maps for flood-prone communities so that the process followed and products produced are similar regardless of which USGS office is responsible for the work (USGS, 2017a). Tasks specific to development of the flood maps for Auburn, Ind. were (1) collection of topographic and bathymetric data for selected cross sections and geometric data for the bridges at First Street, Highway 8, Ninth Street, an abandoned railroad, 19th Street, Auburn Drive, the Baltimore and Ohio railroad, two pedestrian walkways (park bridges), two utility service bridges, and a bridge to the fairgrounds; (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 USACE Hydrologic Engineering Center's River Analysis System (HEC–RAS) computer program (USACE, 2017); (4) production of estimated flood-inundation maps at various stream stages using the USACE HEC–GeoRAS computer program (USACE, 2011) and a GIS; and (5) 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 seven flood-inundation maps in this study were simulated by using HEC–RAS, version 5.0.3 (USACE, 2017). HEC–RAS is a step-backwater model for simulation of water-surface profiles with steady-state (gradually varied) or unsteady-state flow computation options. The HEC–RAS analysis for this study was done using the steady-state (gradually varied) flow computation option.

Hydrologic Data

The study reach consists of one streamgage 04179520 (fig. 1; table 1), which has been in operation since September 2001 and is colocated with the NWS Advanced Hydrologic Prediction Service site ABBI3. The streamgage has a continuous record of measured water level (stage) and computed streamflow. Stage is measured every 15 minutes, transmitted hourly by a satellite radio in the streamgage, and made available on the internet through the USGS National Water Information System (NWIS; USGS, 2017e). Stage data from this streamgage are referenced to a local datum but can be converted to water-surface elevations referenced to the North American Vertical Datum of 1988 (NAVD 88) by adding 843.54 ft. The current datum at the Cedar Creek gage is

844.02 ft above National Geodetic Vertical Datum of 1929 (NGVD 29) (table 1). In order to compare elevations with the channel surveys, which are in NAVD 88, a -0.48 ft height conversion from the VERTCON utility was applied (National Geodetic Survey, 2017). Continuous records of streamflow are computed from a stage-discharge relation, which has been developed for the streamgage, and are available through the USGS NWIS web site (USGS, 2017c).

The steady-flow data necessary for the hydraulic model consisted of boundary conditions (normal depth) and peak-discharge information. The peak flows used in the model simulations (table 3) were taken from the current stage-discharge relation (USGS rating number 1.2, effective May 3, 2017) for streamgage 04179520 and corresponded with the target stages. All computations used discharge values with known stages from actual streamflow measurements or the stage-discharge relation at the gage. No major tributaries join Cedar Creek within the 1.9 mi study reach; therefore, the gage-derived discharges were not adjusted for tributary inflows but were held constant throughout the study reach for a given profile.

Topographic and Bathymetric Data

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 were obtained from a digital elevation model (DEM) that was derived from light detection and ranging (lidar) data that were collected as part of a statewide project during 2011–13 by Woolpert, Inc. (2011). The lidar data for Dekalb County were collected in 2013. The DEM was obtained from the Indiana Spatial Data Portal (Indiana University, 2013). The original 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. By these criteria, the lidar data support production of 2-ft contours (Dewberry, 2012); the final DEM, which was resampled to a grid-cell size of 5 ft by 5 ft to decrease the GIS processing time, has a vertical accuracy of plus or minus 1 ft. By using HEC–GeoRAS (a set of procedures, tools, and utilities for processing geospatial data in ArcGIS), elevation data were extracted from the DEM for 36 cross sections. These data subsequently were input to the HEC–RAS model.

Because lidar data cannot provide ground elevations below the water surface of a stream, channel cross sections were surveyed by USGS field crews during November 2016. Cross-sectional depths were measured by using hydroacoustic instrumentation at 24 locations. A differential global positioning system with real-time kinematic technology was used to derive horizontal locations and the elevation of the water surface at each surveyed cross section. Georeferenced cross sections were made to coincide with the locations of the within-channel field-surveyed cross sections, using the HEC–GeoRAS program, version 10.2. HEC–GeoRAS is a set of procedures, tools and utilities for processing geospatial data in ArcGIS and was used to extract elevation data from the DEM for 24 cross sections. For these 24 cross sections, within-channel field data were directly merged with the DEM data.

The DEM-generated cross section data were used in conjunction with the RAS Mapper tool in HEC–RAS 5.0.3 to interpolate below-water ground elevations through the study reach (USACE, 2017). The RAS Mapper creates an interpolation surface between each cross section. The interpolated surface is then used with the DEM-generated cross section data to create a grid of elevation data in between two cross sections. In this study, a grid of 5 ft by 5 ft was created for the in-channel DEM. The merged DEM of the lidar and in-channel data was used to create the remaining 17 DEM-generated cross sections in HEC–GeoRAS, for input to the HEC–RAS model. The 41 cross-section lines were drawn to best represent flow vectors in the channel and flood plain. Instructions for creation of a terrain model of the channel data are presented in Chapter 2 of the HEC-RAS 2D Modeling User’s Manual (USACE, 2016).

Table 3. Estimated discharges for corresponding stages and water-surface elevations at U.S. Geological Survey streamgage Cedar Creek at 18th Street at Auburn, Indiana (station number 04179520).

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

Stage of water-surface profile (ft)	Water-surface elevation (ft, NAVD 88)	Estimated discharge[2] at USGS streamgage number 04179520 (ft³/s)
7	850.54	869
8	851.54	1,110
9	852.54	1,360
10	853.54	1,630
11	854.54	1,910
12	855.54	2,200
13	856.54	2,490

[1]Discharge from U.S. Geological Survey rating number 1.2, effective March 11, 2009.

Hydraulic Structures

Twelve structures, consisting of bridges at seven road crossings (First Street, Highway 8, Ninth Street, an abandoned railroad, 18th Street, Auburn Drive, and the Baltimore and Ohio railroad), two pedestrian walkways (park bridges), two utility service bridges, and a bridge to the fairgrounds have the potential to affect water-surface elevations during floods along the river. Bridge-geometry data were obtained from field surveys conducted by personnel from the USGS Indiana-Kentucky Water Science Center using a differential global positioning system with real-time kinematic technology.

Energy-Loss Factors

Hydraulic analyses require the estimation of energy losses that result from frictional resistance exerted by a channel on flow. These energy losses are quantified by the Manning's roughness coefficient (*n*-value) (Arcement and Schneider, 1989). Initial (precalibration) *n*-values were selected based on field observations and high-resolution aerial photographs. An *n*-value of 0.031 was selected for the main channel because it is natural, fairly clean, and low gradient. An *n*-value of 0.09 was used for the overbank areas, which are dominated by agricultural fields and forest in the rural sections of the study reach, and the residential and commercial areas of Auburn both east and west of the creek.

The initial *n*-values were adjusted as part of the calibration process, which involved minimizing the differences between simulated and observed water-surface elevations at the streamgage and elsewhere along the study reach. Roughness-coefficient adjustment factors were varied by flow and adjusted until the simulated water-surface elevations approximated the target water-surface elevations. The actual *n*-values were computed by multiplying the initial *n*-value by each of the roughness-coefficient adjustment factors. Main channel *n*-values ranged from 0.029 to 0.040, and overbank values ranged from 0.085 to 0.17.

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 sections that matched target water-surface elevations within 0.36 ft of the current rating for streamgage 04179520. These target elevations coincided with even 1-ft increments of stage, referenced to the local streamgage. Subcritical (tranquil) flow regime was assumed for the simulations. Normal depth, based on an estimated average water surface slope of 0.0021 at the downstream end of the study reach, was used as the downstream boundary condition of the reach. The peak flows that were used in the model are discussed in the "Hydrologic Data" section.

The hydraulic model was calibrated to the most current stage-discharge relation at Cedar Creek streamgage and to the documented high-water marks from the flood of March 11, 2009. Model calibration was accomplished by adjusting Manning's *n*-values until the results of the hydraulic computations closely agreed with the observed water-surface elevations for given flows. Absolute differences between target and simulated water-surface elevations for the seven simulated flows at the USGS streamgage were equal to or less than 0.36 ft (table 4). Differences between surveyed high-water marks from the flood of March 11, 2009 and simulated water-surface elevations were equal to or less than 0.98 ft (table 5). The results demonstrate that the model is capable of simulating accurate water levels over a wide range of flows in the study reach.

Table 4. Calibration of hydraulic model to target water-surface elevations at U.S. Geological Survey streamgage Cedar Creek at 18th Street at Auburn, Indiana (station 04179520).

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

Stage of water-surface profile (ft)	Target water-surface elevation (ft, NAVD 88)	Simulated water-surface elevation (ft, NAVD 88)	Elevation difference (ft)
7.00	850.54	850.78	0.24
8.00	851.54	851.70	0.16
9.00	852.54	852.44	–0.10
10.00	853.54	853.32	–0.22
11.00	854.54	854.20	–0.34
12.00	855.54	855.30	–0.24
13.00	856.54	856.18	–0.36

Table 5. Calibration of hydraulic model to water-surface elevations at selected locations along Cedar Creek at Auburn, Indiana, for the flood of March 11, 2009.

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

River station (ft)[1]	Surveyed high-water mark elevation (ft, NAVD 88)[2]	Modeled water-surface elevation (ft, NAVD 88)[3]	Elevation difference (ft)
1,570.00	849.81	849.02	–0.79
1,939.60	850.10	849.70	–0.40
2,203.60	850.38	850.16	–0.22
2,626.00	851.67	850.78	–0.89
2,890.00	851.81	851.22	–0.59
3,259.60	851.87	851.56	–0.31
3,523.60	852.14	851.86	–0.28
4,474.00	853.83	852.90	–0.93
4,685.20	854.17	853.19	–0.98
5,107.60	854.13	854.03	–0.10
5,371.60	854.34	854.21	–0.13
6,480.40	855.68	855.15	–0.53
6,586.00	855.71	855.31	–0.40
6,902.80	855.99	856.18	–0.19
7,061.20	855.95	856.25	–0.30
8,645.20	857.35	856.86	–0.49
8,909.20	857.37	856.99	–0.38
9,331.60	857.84	857.47	–0.37
9,701.20	858.28	858.05	–0.23
9,859.60	858.31	858.13	–0.18
10,229.20	858.81	858.31	–0.50
10,387.60	858.39	858.36	–0.03

[1]River station references the distance upstream to the high-water mark from the most downstream point (starting point) in the hydraulic model.

[2]Elevations surveyed by Indiana Department of Natural Resources.

[3]Elevation from hydraulic model profile.

Development of Water-Surface Profiles

The calibrated hydraulic model was used to generate water-surface profiles for a total of seven stages at 1-ft intervals between 7 ft and 13 ft as referenced to the Cedar Creek streamgage. These stages correspond to elevations between 850.54 ft and 856.54 ft, NAVD 88.

Development of Flood-Inundation Maps

Flood-inundation maps were created in a GIS for the seven water-surface profiles by combining the profiles and digital elevation model data. The DEM data were derived from the same lidar data described previously in the "Topographic and Bathymetric Data" section and therefore have an estimated vertical accuracy of 2 ft (that is, plus or minus 1 ft). Estimated flood-inundation boundaries for each simulated profile were developed with HEC–GeoRAS software (USACE, 2011), which allows the preparation of geometric data for import into HEC–RAS and processes simulation results exported from HEC–RAS (USACE, 2017). Shapefile polygons and depth grids of the inundated areas for each profile were modified, as required, in the ArcMap application of ArcGIS to ensure a hydraulically reasonable transition of the flood boundaries between modeled cross sections. The datasets used in this study are available through a data release at https://doi.org/10.5066/F72806GR (Fowler, 2017).

Any inundated areas that were detached from the main channel were examined to identify subsurface connections with the main stream, such as through culverts under roadways. Where such connections existed, 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." The flood-inundation map corresponding to the highest simulated water-surface profile, a stage of 13.0 ft, is presented in figure 2. A stage of 13.0 ft is based on the extended rating, number 1.2, and is 0.7 ft above the highest measured discharge.

Flood-Inundation Map Delivery

The current study documentation is available online at the USGS Publications Warehouse (https://doi.org/10.3133/sir20175156). Also, a Flood Inundation Mapping Science web site (USGS, 2017b) has been established to make USGS flood-inundation study information available to the public; that Flood Inundation Mapping Science web site links to a mapping application that presents map libraries and provides detailed information on flood extents and depths for modeled sites. The mapping application enables the production of customized flood-inundation maps from the map library for Cedar Creek at 18th Street at Auburn, Ind. A link on this web site connects to the USGS NWIS (USGS, 2017c), which presents the current stage and streamflow at USGS streamgage 04179520 to which the flood-inundation maps are referenced. A second link connects to the NWS Advanced Hydrologic Prediction Service site (NWS, 2017) so that the user can obtain applicable information on stage. The estimated flood-inundation maps are displayed in sufficient detail so that preparations for flooding and decisions for emergency response can be performed efficiently. According to model output, some of the first public areas to experience flooding are the county fairgrounds and Eckhart Park at a stage between 6 and 7 ft. 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 indicate 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. The flood boundaries shown were estimated on the basis of water stages and streamflows at a selected USGS streamgage. 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, embankment, or other hydraulic structures existing as of November 2016. 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

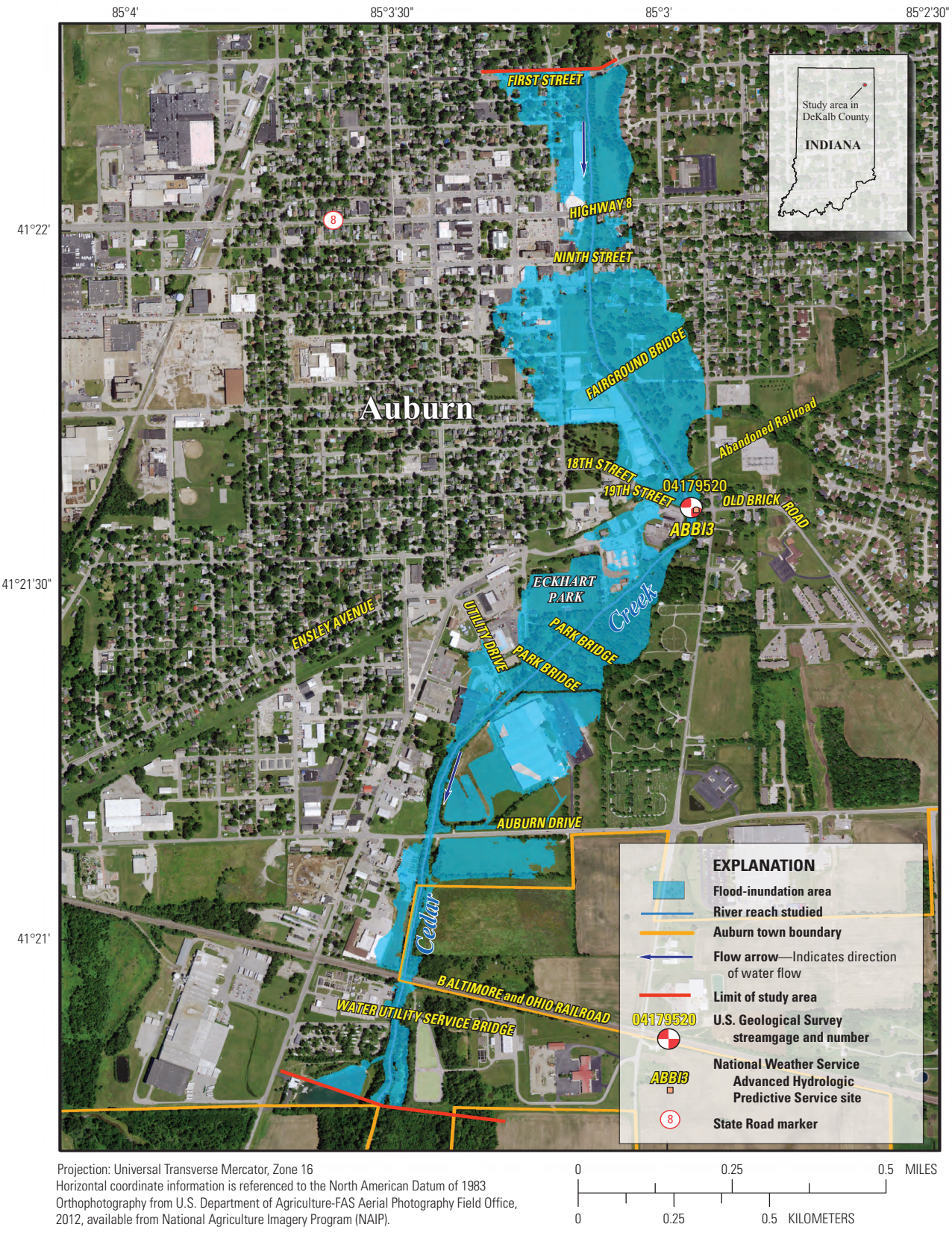

Figure 2. Flood-inundation map for Cedar Creek at 18th Street at Auburn, Indiana, corresponding to a stage of 13.0 feet* at the U.S. Geological Survey streamgage (station number 04179520).

*Thirteen feet is based on the extended rating curve and is 0.7 feet higher than the peak gage height.

boundaries shown. Additional areas may be flooded because of unanticipated conditions such as changes in the streambed elevation or roughness, backwater into tributaries along a main stem river, blockage of water due to earthen embankments, 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.

Summary

A series of seven digital flood-inundation maps were developed in cooperation with the Indiana Department of Transportation for a 1.9-mile reach of Cedar Creek at Auburn, Indiana (Ind.). The stream reach flows from the First Street bridge, downstream to the streamgage at 18th Street, then ends approximately 1,100 feet (ft) downstream of the Baltimore and Ohio railroad bridge. The maps were developed by using the U.S. Army Corps of Engineers' Hydrologic Engineering Center's River Analysis System (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 Cedar Creek streamgage at 18th Street at Auburn (04179520) and the documented high-water marks from the flood of March 11, 2009. The model was used to compute seven water-surface profiles for flood stages referenced to the streamgage datum and ranging from 7 ft, or just above bankfull, to 13.0 ft. The simulated water-surface profiles were then combined with a geographic information system digital elevation model derived from light detection and ranging 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 flood maps are available through a mapping application that can be accessed on the U.S. Geological Survey (USGS) Flood Inundation Mapping Science web site (https://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 cursor to click within the shaded areas. The mapping application enables the production of customized flood-inundation maps from the map library for Cedar Creek at 18th Street at Auburn, Ind. These maps, in conjunction with the real-time stage data from the USGS streamgage, Cedar Creek at 18th Street at Auburn, Ind. (station number 04179520), and flood stage data from the National Weather 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.

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Cover back, upper. Cedar Creek at 18th Street at Auburn, Indiana, Upstream Channel. September 7, 2016.

Cover back, lower. Cedar Creek at 18th Street at Auburn, Indiana, Upstream Channel. December 21, 2015.

All photos taken by U.S. Geological Survey personnel.

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