

Prepared in cooperation with the
City of Lansing, Michigan, and U.S. Army Corps of Engineers

Flood-Inundation Maps for Grand River, Red Cedar River, and Sycamore Creek near Lansing, Michigan



Scientific Investigations Report 2015–5101
Version 1.1 February 2016

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

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By Matthew T. Whitehead and Chad J. Ostheimer

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Conversion Factors

Inch/Pound to SI

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)	0.0283	cubic meter per second (m ³ /s)

Vertical coordinate information is referenced to (1) stage, the height above an arbitrary datum established at a streamgauge, and (2) elevation, the height above the North American Vertical Datum of 1988 (NAVD 88).

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

Flood-Inundation Maps for Grand River, Red Cedar River and Sycamore Creek near Lansing, Michigan

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Abstract

Digital flood-inundation maps for a total of 19.7 miles of the Grand River, the Red Cedar River, and Sycamore Creek were created by the U.S. Geological Survey (USGS) in cooperation with the City of Lansing, Michigan, and the U.S. Army Corps of Engineers. The flood-inundation maps, which can be accessed through the USGS Flood Inundation Mapping Science Web site at http://water.usgs.gov/osw/flood_inundation/, show estimates of the areal extent and depth of flooding corresponding to selected water levels (stages) at three USGS streamgages: Grand River at Lansing, MI (04113000), Red Cedar River at East Lansing, MI (04112500), and Sycamore Creek at Holt Road near Holt, MI (04112850). Near-real-time stages at these streamgages can be obtained on the Internet from the USGS National Water Information System at <http://waterdata.usgs.gov/> or the National Weather Service (NWS) Advanced Hydrologic Prediction Service at <http://water.weather.gov/ahps/>, which also forecasts flood hydrographs at all of these sites.

Each set of flood profiles was computed by means of a one-dimensional step-backwater model. Each model was calibrated to the current stage-discharge relation at each streamgage and to water levels determined with stage sensors (pressure transducers) temporarily deployed along each stream reach. The hydraulic model was used to compute a set of water-surface profiles for flood stages from nearly Action Stage to above Major Flood stage, as reported by the National Weather Service. The computed water-surface profiles were then used in combination with a geographic Information System digital elevation model derived from light detection and ranging (lidar) data to delineate the approximate areas flooded at each water level.

These maps, used in conjunction with real-time USGS streamgage data and NWS forecasting, provide critical information to emergency management personnel and the public. This information is used to plan flood response actions, such as evacuations and road closures, as well as aid in postflood recovery efforts.

Introduction

Low-lying areas adjacent to the Grand River, the Red Cedar River, and Sycamore Creek in the Lansing, Michigan, area are subject to periodic flooding. A history of significant and repetitive flooding is well documented for these low-lying areas within central Lansing and East Lansing (City of Lansing, 2015). The City of Lansing estimates that about 1,700 residents and 250 businesses are at risk for flood damage (Ronda Oberlin, City of Lansing, oral commun, 2012).

Prior to this study, emergency responders near Lansing relied on several information sources to help 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 Ingham County (Federal Emergency Management Agency, 2011). A second source is U.S. Geological Survey (USGS) streamgage data for the Grand River, the Red Cedar River, and Sycamore Creek, for which current (U.S. Geological Survey, 2015a, b, c) and historical (U.S. Geological Survey, 2015d) water levels and flows (including annual-peak flows) can be obtained. A third source of flood-related information is the National Weather Service (NWS) Advanced Hydrologic Prediction Service (AHPS), which displays the USGS stage data from the streamgages and also shows forecasted stages for each of the three streamgages (National Weather Service, 2015a, b, c).

Although the current stage at a USGS streamgage can be useful for residents in the immediate vicinity of a streamgage, it is less useful 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 not easily translated into depth and areal extent of flooding at points distant from the streamgage. One way to address this problem is to produce a library of flood-inundation maps that are referenced to stages recorded at the USGS streamgages. By examining the appropriate maps, emergency responders can estimate projected severity of flooding (depth of water and areal extent), identify roads that are or may soon be flooded, and make plans for notification or evacuation

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of residents in harm's way for some distance upstream and downstream from the streamgage. In addition, visualizing the potential extent of flooding motivates residents to take precautions and heed warnings that might otherwise be disregarded.

Purpose and Scope

This report describes the development of a series of flood-inundation maps for the Grand River, the Red Cedar River, and Sycamore Creek near Lansing, Mich. (fig. 1). Report findings may also be downloaded for a total of 19.7 miles (mi) (table 1) of study reaches. The maps associated with this report were produced for flood levels referenced to 1-foot (ft) stages recorded at each of the three USGS streamgages (table 2) and have a range of near Action Stage to above Major Flood Stage (table 3) as designated by the National Weather Service (National Weather Service, 2015d).

For the remainder of this report, the USGS streamgage Grand River at Lansing, MI (04113000) will be referred to as the "Grand River streamgage." The Red Cedar River at East Lansing (04112500) streamgage will be referred to as the "Red Cedar River" streamgage, and the Sycamore Creek at Holt Road, near Holt, MI (04112850) will be referred to as the "Sycamore Creek streamgage."

Drainage areas were obtained from the NHD version 2 catchments (U.S. Environmental Protection Agency and U.S. Geological Survey, 2012), selected by tracing upstream from a point of interest. The catchment for a point of interest was clipped to remove downstream area by referencing USGS topographic maps for the appropriate area.

Study Area Description

Lansing is in the lower peninsula of Michigan, about 70 mi north of the Ohio-Michigan State line. Lansing is mostly contained in the northwest corner of Ingham County, with a small portion in the county to the west, Eaton County. The largest river in Lansing is the Grand River, which bisects the city's downtown area. The Red Cedar River enters the Grand River just upstream (south) from the downtown area of Lansing. Sycamore Creek enters the Red Cedar River about 1 mi upstream (southeast) from the mouth of the Red Cedar River.

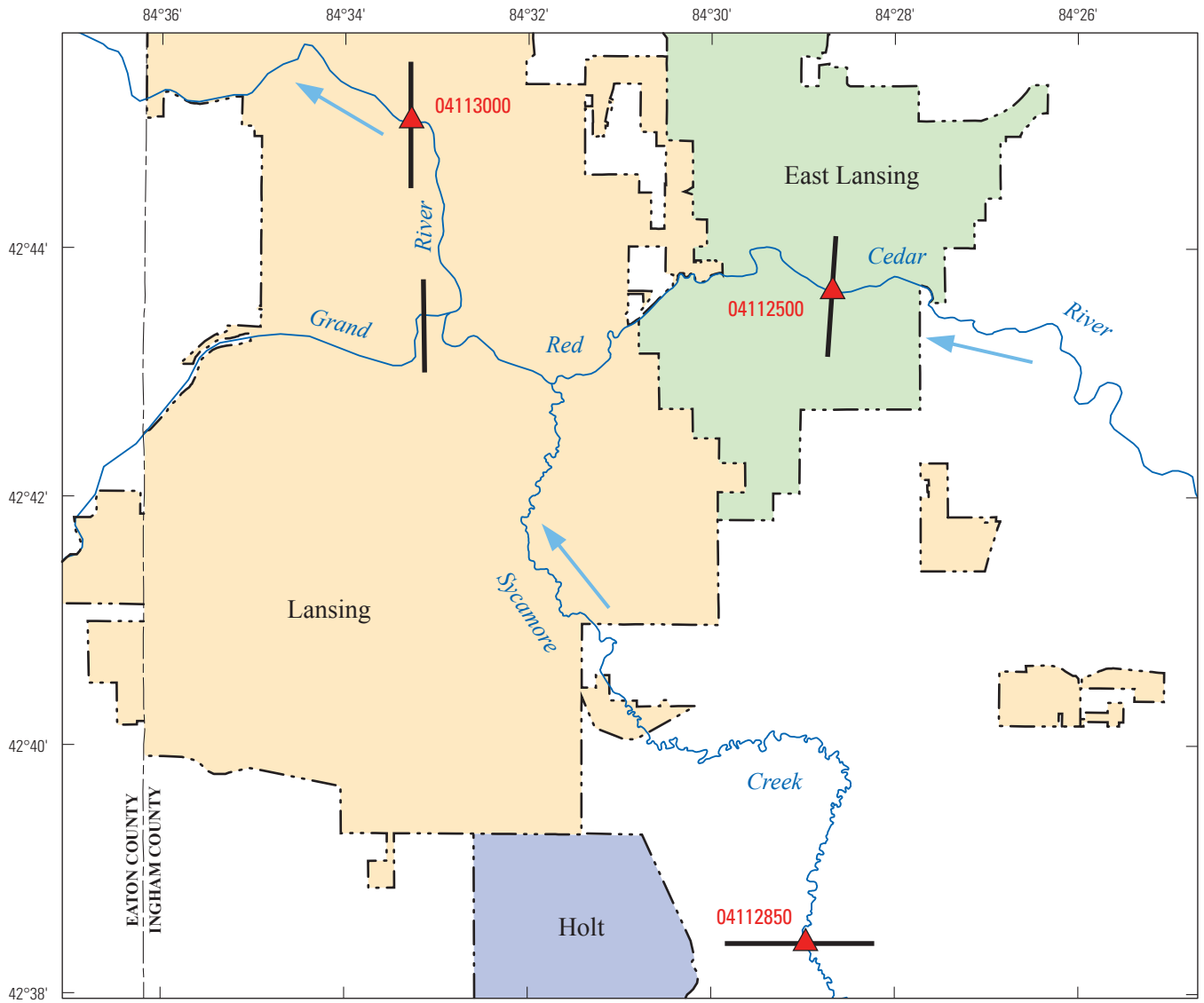
The drainage areas of the three streams include both rural and urban areas. Within the study limits of this project, the Grand River drainage is in an entirely urban area (Lansing), the Red Cedar River drainage is mostly urban (Lansing and East Lansing), and the Sycamore Creek drainage is mostly marshy wetlands.

Previous Studies

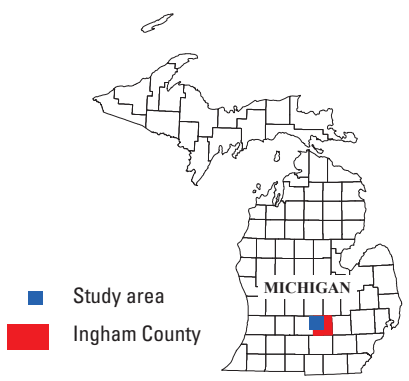
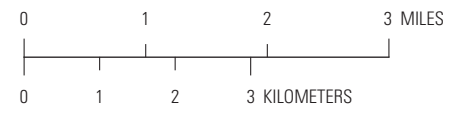
The current FIS for Ingham County, Michigan (Federal Emergency Management Agency, 2011) was published in 2011. Areas prone to major floods, corresponding to 10-, 2-, 1-, and 0.2-percent annual chances of flooding (also referred to as the 10-, 50-, 100-, and 500-year floods) were redelineated as part of the revision of the FIS. The redelineations were based on topographic information developed using light detection and ranging (lidar) data collected in 2003. The 2011 FIS did not include any new hydrology or hydraulics, only a redelineation of the flood-plain boundaries on the newest (2003) topography.

The regulated flood elevations are based upon hydraulic data and hydrologic analyses completed in May 1978. In particular, field surveys of stream channels and bridge geometry reflect the conditions of more than 35 years ago. The topography of overbank areas was determined from topographic maps developed from aerial photography in 1978. These data were entered into a hydraulic model used to compute flood elevations based on flow values established from flood frequency-magnitude computations. These frequency-magnitude computations were themselves based on data available through 1978 at U.S. Geological Survey (2015a, b, c) streamgages Grand River at Lansing, MI (04113000), Red Cedar River at East Lansing, MI (04112500), and Sycamore Creek at Holt Road near Holt, MI (04112850).

As a result, the 2011 FIS report does not include updated hydraulic modeling to reflect changes in the natural channel and (or) hydraulic structures since 1978, nor does it include updated hydrologic analyses reflecting an additional 35 years of annual peak-flow data. Given the limitations of the FEMA 2011 FIS revision, the inundation maps for the Lansing area described in this report are based on a new hydraulic model incorporating data from new field surveys of the three stream channels, current geometries of hydraulic structures, and overbank geometry obtained from the latest Tri-County Regional Planning Commission lidar survey (2010).



Base from U.S. Geological Survey digital data, variously scaled, 2014 Geographic projection, North American Datum of 1983.



EXPLANATION


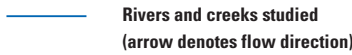


-  Corporate limits
-  Rivers and creeks studied (arrow denotes flow direction)
-  Stream study limits
-  USGS streamgage and identifier

Figure 1. Locations of selected streamgages and rivers and creeks.

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Table 1. Description of study reaches.

River or creek name	Reach length square mile	Upstream limit of study reach	Downstream limit of study reach
Grand River	2.3	South Washington Avenue bridge, Lansing, Michigan	USGS streamgage, Grand River at Lansing, Michigan
Red Cedar River	5.4	USGS streamgage, Red Cedar Creek at East Lansing, Michigan	Mouth (confluence with Grand River)
Sycamore Creek	12.0	USGS streamgage, Sycamore Creek at Holt Road near Holt, Michigan	Mouth (confluence with Red Cedar River)

Table 3. Minimum and maximum target water-surface stages and National Weather Service designated stages for Grand River, Red Cedar River, and Sycamore Creek.

[ft, feet]

River or creek name	Minimum stage included in this report (ft)	Maximum stage included in this report (ft)	Action stage ¹ (ft)	Major flood stage ¹ (ft)
Grand River	13.0	21.0	10.0	15.0
Red Cedar River	8.0	14.0	7.0	10.5
Sycamore Creek	6.0	11.0	6.0	10.0

¹As reported by the National Weather Service at <http://water.weather.gov/ahps2/index.php?wfo=dtx>.

Table 2. U.S. Geological Survey streamgage information for the Grand River, the Red Cedar River, and Sycamore Creek near Lansing, Michigan.

[DA, drainage area; mi², square miles; ft, feet; ft³/s, cubic feet per second; NAVD 88, North American Vertical Datum of 1988]

Station name	Station number	DA (mi ²)	Latitude	Longitude	Period of peak-flow record	Maximum recorded stage (ft) and date	Maximum flows (ft ³ /s) and date	Gage datum (ft above NAVD 88)
Grand River at Lansing, MI	4113000	1,230	42°45'02"	84°33'19"	1901–2014	18.60 Mar. 26, 2004	24,500 Mar. 26, 2004	804.92
Red Cedar River at East Lansing, MI	4112500	344	42°43'38"	84°28'41"	1903–1904 1911–2014	13.40 Mar. 24, 2004	8,000 ¹ Mar. 24, 2004	823.96
Sycamore Creek at Holt Road, near Holt, MI	4112850	80	42°38'25"	84°28'58"	1975–1997	10.00 Apr. 19, 1975	2,110 Apr. 19, 1975	844.89

¹Flow is an estimate.

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, 2015e) so that the process followed and products produced are similar regardless of which USGS office is responsible for the work. Tasks specific to development of the flood maps were (1) reestablishment of one streamgage (table 1) on Sycamore Creek, (2) collection of topographic and bathymetric data for selected cross sections and geometric data for structures and bridges along each study reach, (3) estimation of energy-loss factors (roughness coefficients) in the stream channel and flood plain, (4) computation of water-surface profiles using the U.S. Army Corps of Engineers' Hydrologic Engineering Center – River Analysis System (HEC–RAS) computer program (U.S. Army Corps of Engineers, 2010), (5) production of flood-inundation maps corresponding to selected stream stages by use of the U.S. Army Corps of Engineers' HEC–GeoRAS computer program (U.S. Army Corps of Engineers, 2009) and a geographic information system (GIS), and (6) preparation of map products for a USGS floodinundation mapping application that show the areal extent of flooding and water depths for display on a USGS floodinundation mapping application.

Computation of Water-Surface Profiles

The water-surface profiles used to produce the flood-inundation maps in this study were computed by using HEC–RAS, version 4.1.0 (U.S. Army Corps of Engineers, 2010). HEC–RAS is a one-dimensional step-backwater model used for simulation of water-surface profiles with steady-state (gradually varied) or unsteady-state flow computation options.

Hydrologic Data

The study reaches include three streamgages (table 2). Two of the gages were already in operation with continuous recorders, and one streamgage (Sycamore Creek) was reestablished for this project. 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; U.S. Geological Survey, 2015a, b, c).

For each streamgage, the current¹ stage-discharge relation (rating) was used to determine the flow for each study reach corresponding to the target stage value. For each stream, the rating (table 4) was extended (using HEC–RAS) to include target stages higher than the current rating provided. Because the streamgages for the Red Cedar River and Sycamore Creek are at the upstream ends of their respective study reaches,

streamflows were increased at selected downstream locations (fig. 2) to account for the gradual increase in drainage-area size (table 5). Because there are no drainage-area-only equations for peak flows at ungaged locations in Michigan, a straight drainage-area ratio was used to compute increases in discharge downstream of the gages. In addition, the streamflows for the Red Cedar River below Sycamore Creek were increased to include inflows corresponding to the various target stages of Sycamore Creek. Because the Grand River streamgage is at the downstream end of its study reach, streamflows were decreased above the Red Cedar River to account for inflows corresponding to the various target stages of the Red Cedar River.

Topographic and Bathymetric Data

Cross-section elevation data were obtained from a digital elevation model (DEM) that was derived from lidar data collected during March 2010. The original lidar data have horizontal resolution of 3.8 ft (1.2 meters) and vertical accuracy of 0.49 ft (15 centimeters) at a 95-percent confidence level for the “open terrain” land-cover category. By these criteria, the lidar data support production of 2-ft contours (Dewberry, 2012). The 4- by 4-ft-resolution DEM was provided to the USGS by the Tri-County Regional Planning Commission (2010), and the USGS created 1-ft contour lines from the DEM data using ArcGIS.

By using HEC–GeoRAS (USACE, 2009)—a set of procedures, tools, and utilities for processing geospatial data in ArcGIS—elevation data were extracted from the DEM for 422 cross sections and input to the HEC–RAS model. The cross-sectional spacing is 210 ft on average, and the maximum distance between sections is 497 ft.

Because standard lidar data do not provide ground elevations below a stream's water surface, channel cross sections were surveyed by USGS field crews during 2013. Cross-sectional depths were measured by conventional (total station) surveying techniques or by using hydroacoustic instrumentation at 176 locations. A differential global positioning system (DGPS) with realtime kinematic (RTK) technology was used to derive horizontal locations and the elevation of the water surface at each surveyed cross section. Elevations determined by RTK DGPS at six benchmark locations were within 0.02–0.13 ft of the known elevations, an error range that is better than the accuracy of the lidar data.

DEM-generated cross sections were collocated with the locations of the within-channel field-surveyed cross sections. In these cases, within-channel data were directly merged with the DEM data. For all other cross sections, the within-channel data were estimated by interpolation from the closest field-surveyed cross section. In-channel data were surveyed upstream and downstream from every hydraulic structure. Additional cross sections were surveyed to ensure that no reach length between surveyed cross sections was greater than 1 mi.

¹At the time of this report, the current rating for Grand River is 15.0, Red Cedar is 16.0 and Sycamore Creek is 6.0.

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Table 4. Selected stages and associated streamflows for respective stage-discharge relations for the Grand River, Red Cedar River, and Sycamore Creek streamgages referred to in this report.

[ft, feet; ft³, cubic feet per second; **bolded** values indicate data that exceed the range of the current ratings¹]

Grand River rating #15, effective 10/2006		Red Cedar River rating #16, effective 10/1999		Sycamore Creek rating #6, effective 10/1995	
Stage (ft)	Streamflow (ft ³ /s)	Stage (ft)	Streamflow (ft ³ /s)	Stage (ft)	Streamflow (ft ³ /s)
13	8,390	8	2,650	6	170
14	9,520	9	3,440	7	317
15	10,700	10	4,240	8	599
16	12,000	11	5,130	9	944
17	13,200	12	5,970	10	1,550
18	14,600	13	6,960	11	2,270
19	16,000	14	8,070		
20	17,500				
21	19,000				

¹ At the time of this report, the current rating for Grand River is 15.0, Red Cedar is 16.0 and Sycamore Creek is 6.0.

Table 5. Drainage areas at selected locations for the Red Cedar River and Sycamore Creek.

[DA, drainage area]

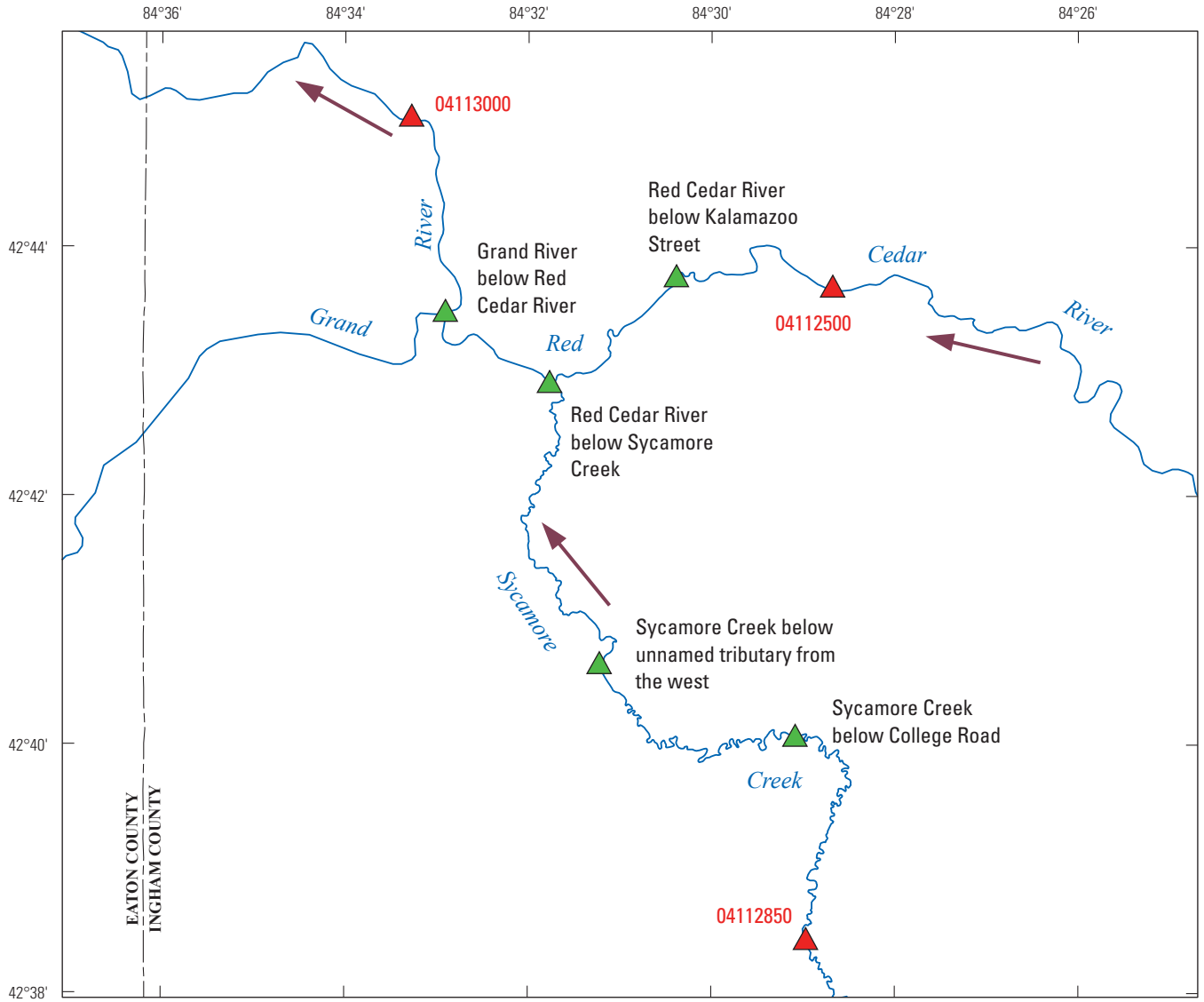
Location	River station ¹	DA (square miles)	Percentage of DA (percent)
Red Cedar River			
Streamgage	28,300	344	100.0
Below Kalamazoo Street	17,485	349	101.5
Below Sycamore Creek	7,805	459	133.4
Sycamore Creek			
Streamage	63,320	80.0	100.0
Below College Road	43,256	83.9	104.9
Below unnamed tributary from west	21,586	88.1	110.1

¹River stations are referenced to the longitudinal baseline used in the hydraulic model, referenced to the mouth.

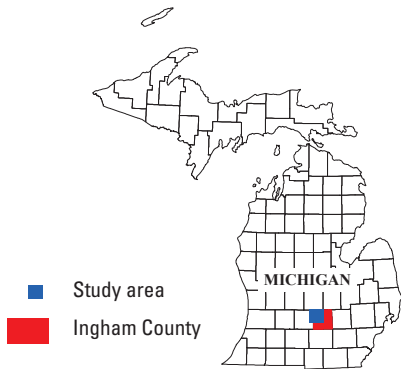
Hydraulic Structures

Along the selected stream reaches, there are 43 structures (road crossings, railroad bridges, and walk paths) and 2 dams that may affect water-surface elevations during floods. Structure-geometry data were obtained from field surveys conducted by personnel from the USGS Michigan-Ohio Water Science Center using RTK DGPS and conventional surveying techniques.

It should be noted that the North Lansing Dam (fig. 3), which is maintained and operated by the Lansing Board of Water and Light, has multiple (manually operated) gate settings that affect water-surface elevations. The dam has four gates that are usually positioned in one of three configurations: (1) all gates up, (2) gate 1 down with gates 2, 3, and 4 up, and (3) all gates down (Jessica Harbitz, Lansing Board of Water and Light, written commun., 2012). At the request of the study partners, and assuming a “worst-case scenario” with respect to flood elevations, all hydraulic modeling (and subsequent flood-plain delineations) included in this report reflect only the configuration of all gates up (closed).



Base from U.S. Geological Survey digital data, variously scaled, 2014 Geographic projection, North American Datum of 1983.

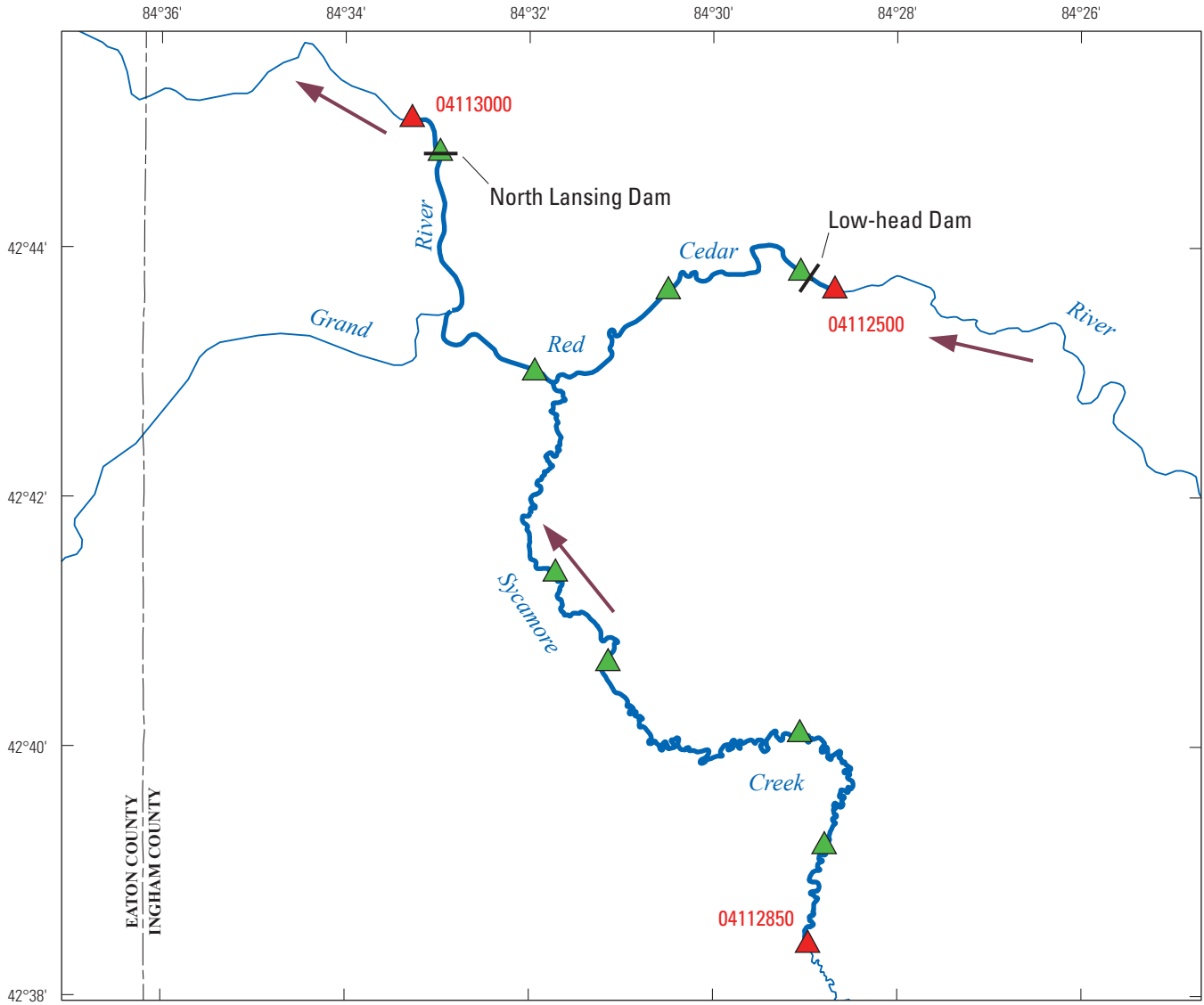


EXPLANATION

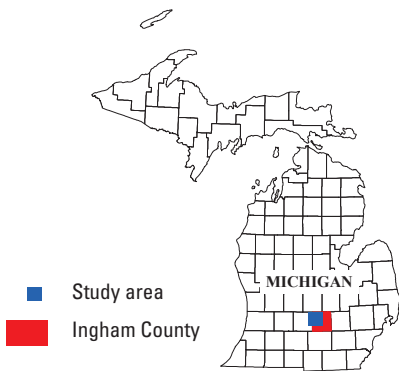
- Rivers and creeks studied (arrow denotes flow direction)
- ▲ Streamflow change location
- ▲ 04112850 USGS streamgage and identifier

Figure 2. Locations of increased flows due to increased drainage area.

8 Flood-Inundation Maps for Grand River, Red Cedar River and Sycamore Creek near Lansing, Michigan



Base from U.S. Geological Survey digital data, variously scaled, 2014 Geographic projection, North American Datum of 1983.



EXPLANATION

- Rivers and creeks studied (arrow denotes flow direction)
- Study reaches
- Dams
- ▲ Stage sensors
- ▲ 04112850 USGS streamgage and identifier

Figure 3. Locations of selected USGS streamgages and stage sensors near Lansing, Michigan.

Energy-Loss Factors

Hydraulic analyses require the estimation of energy losses exerted by a channel on flow. These energy losses are quantified by the Manning’s roughness coefficient (“*n*” value). Initial (precalibration) *n* values were selected on the basis of field observations and high-resolution aerial photographs.

As part of the calibration process, the initial *n* values were adjusted until the differences between computed and observed water-surface elevations at the streamgage and stage sensors were minimized. The final *n* values ranged from 0.040 to 0.048 for the main channels and 0.036 to 0.100 for the overbank areas modeled in this analysis (table 6).

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 (table 7) coincided with 1ft increments of stage. A subcritical (tranquil) flow regime was assumed for the simulations. The Grand River streamgage is at the downstream end of the study reach, so the boundary condition is a known water-surface elevation, with the values taken from the current rating for the streamgage for each profile. The peak flows that were used in the model were discussed in the section, “Hydrologic Data.”

The Red Cedar River is subject to backwater conditions from the Grand River. Sycamore Creek is subject to backwater

conditions from both the Grand and Red Cedar Rivers. To account for concurrent flooding from multiple streams, the hydraulic model joined the three streams together by means of junctions. As a result, the model used water-surface elevations from the Grand River as downstream boundary conditions for the Red Cedar River and used water-surface elevations from the Red Cedar River as downstream boundary conditions for Sycamore Creek.

Model Calibration

In addition to the target stages at each of the three streamgages, calibration information was obtained by installing stage sensors (pressure transducers) at eight locations along the modeled reaches of the three streams (fig. 3) in March 2014. Surveys were conducted to establish the vertical datum of each stage sensor relative to NAVD 88. The stage sensor elevations were checked, data were downloaded, and the sensors were cleaned twice during their deployment. The stage sensors were removed in July 2014.

Stage data collected during a runoff event in May 2014 provided additional data for model calibration. Streamflow values used to calibrate the HEC–RAS model for the event were obtained from the current rating for each streamgage. After calibration, the modeled elevations and measured elevations (from sensors and streamgages) had a root mean square error of 0.29 ft, with a maximum difference of 0.61 ft (table 8). For reference, this runoff event had the following stages at each of the three stream gages: Grand River, 9.1 ft; Red Cedar River, 7.3 ft; and Sycamore Creek, 8.1 ft.

Table 6. Range in Manning’s roughness factors for selected streams.

Stream	Manning’s <i>n</i> for main channel	Manning’s <i>n</i> for overbank areas
Grand River	0.040–0.042	0.040–0.062
Red Cedar River	0.040–0.046	0.036–0.090
Sycamore Creek	0.042–0.048	0.042–0.100

Table 7. Calibration of model to target water-surface elevations at selected U.S. Geological Survey streamgages.

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

Stage of water-surface profile (ft)	Target water-surface elevation (ft, NAVD 88)	Modeled water-surface elevation (ft, NAVD 88)	Difference in elevation (ft)
Red Cedar River			
8	831.96	832.11	0.15
9	832.96	833.05	0.09
Sycamore Creek			
6	850.89	850.70	0.19
7	851.89	851.91	–0.02
8	852.89	853.00	–0.11

10 Flood-Inundation Maps for Grand River, Red Cedar River and Sycamore Creek near Lansing, Michigan

Table 8. Calibration of model to water-surface elevations at selected locations along selected streams for the flood of May 16, 2014.

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

Description	River station ¹ (ft)	Measured elevation (ft, NAVD 88)	Modeled elevation (ft, NAVD 88)	Difference in elevation (ft)
Lansing Streamgage	68	814.02	814.02	0.00
Stage sensor	3,016	817.41	817.68	0.27
Stage sensor	6,892	821.88	821.78	-0.10
Stage sensor	16,321	825.12	824.81	-0.31
Stage sensor	26,639	829.96	830.02	0.06
East Lansing streamgage	28,300	831.29	831.31	0.02
Stage sensor	13,605	829.13	829.15	0.02
Stage sensor	21,586	835.40	834.88	-0.52
Stage sensor	43,387	844.11	843.50	-0.61
Stage sensor	55,176	848.26	848.21	-0.05
Holt Road streamgage	63,320	853.00	853.07	0.07

¹ River station numbers are referenced to the longitudinal baseline used in the hydraulic model, referenced to the mouth.

Selection of Final Flood Profiles

The total number of possible combinations of profiles is the product of the 9 stages for the Grand River (table 4), 7 for the Red Cedar River, and 6 for Sycamore Creek, or 378 possible combinations. The flow values from table 4 were analyzed to determine combinations that would be likely to occur. Of the 378 combinations, 8 represent combinations where the sum of discharges from the Red Cedar River and Sycamore Creek exceed the total flow in the Grand River. For example, the combination of stage 14 (Red Cedar River) and stage 11 (Sycamore Creek) represent a combined discharge of 10,340 ft³/s, which exceeds the 8,390 ft³/s associated with stage 13 on the Grand River —and, therefore, is an illogical combination (assuming no storage). Removing these 8 illogical combinations leaves 370 possible combinations.

Coincident peak-flow data were obtained from multiple sources for all three stream gages and analyzed (fig. 4). Most data were obtained from USGS records; however, some data were obtained from the National Weather Service (National Weather Service, 2015a, b, c).

The highest percentage of flow from the Red Cedar River and Sycamore Creek to flow in the Grand River occurred in 1975 at 72 percent. The highest percentage of flow from Sycamore Creek to flow in the Red Cedar River occurred in 1979 at 59 percent. Final flood profiles for this report include combinations (flow distributions) where (1) the sum of flows

of the Red Cedar River and Sycamore Creek was less than 72 percent of the flow for the Grand River and (2) the flow for Sycamore Creek was less than 59 percent of the flow for the Red Cedar River. This resulted in a total of 305 profiles. (See appendix 1 for a table of modeled stage combinations.)

Development of Flood-Inundation Maps

A method was devised to map calculated flood-plain boundaries corresponding to each of the 305 final profiles, resulting in approximated flood-plain boundaries. For each set of two adjacent cross sections in a given profile, an average water-surface elevation was calculated and rounded to the nearest foot. This water-surface elevation was then represented by the topo line between adjacent sections. An example of an approximated flood profile for the Grand River is shown in figure 5.

An error analysis of this approximate mapping method showed that, as expected, the maximum and minimum errors between the average water-surface elevation and those rounded to the nearest whole foot were 0.50 ft and -0.50 ft, respectively. The average and average absolute errors were 0.00 ft and 0.25 ft, respectively. This analysis indicates that, on average, the approximately mapped water-surface elevation is within 0.25 ft of the average water-surface elevation or ¼ of the base mapping contour interval and the mapped stage interval.

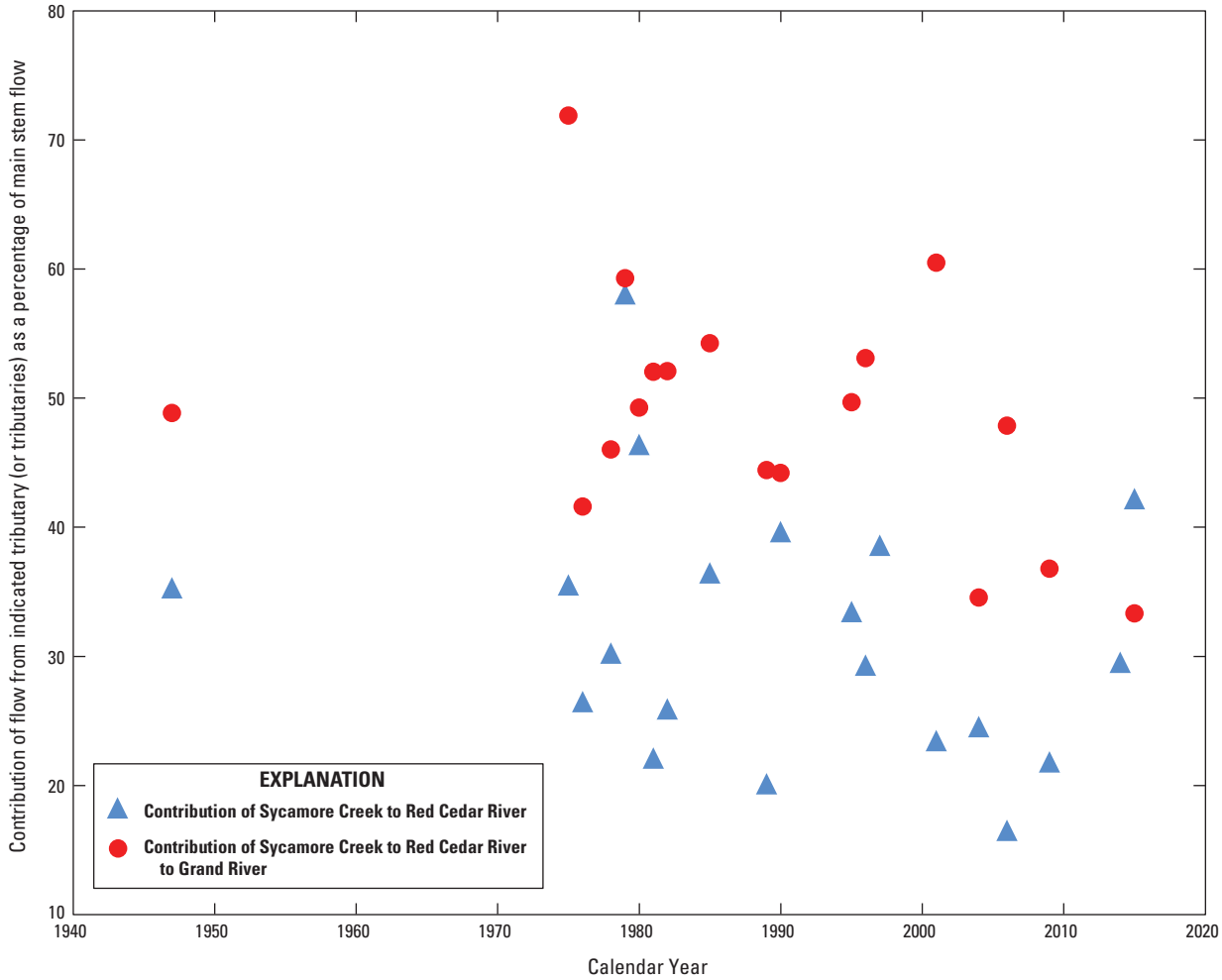


Figure 4. Percentages of tributary flows to main stem flows for selected streams near Lansing , Michigan

In order to create the approximate flood-plain boundaries for the flood profiles, the contours created from the DEM provided (see “Topographic and Bathymetric Data” section) that matched the rounded elevation for each set of adjacent cross sections were selected to produce the flood-plain boundary for each adjacent cross-section segment. The segments were then combined to produce a continuous flood-plain boundary. The amount of longitudinal error for the flood-plain boundaries (fig. 5) for the approximated water-surface elevation varies depending on the width of separation for adjacent topographic lines. The flood-plain boundaries resulting from mapping the approximated water-surface elevations can show (depending on the scale at which the mapping is viewed) disjointed edges or “jumps” in the flood-plain boundaries. Figure 5 shows an example of the estimated flood-plain boundary “jumping” as the approximated water-surface elevation changes from 828 ft to 829 ft. No error analyses were conducted for the longitudinal errors of the “jumps” along the edges of the flood-plain boundaries.

After the flood-plain boundaries for the approximated flood profiles were created, checks were performed to ensure logical transitions. Any inundated areas that were detached from the main channel were examined to identify artificial connections with the main rivers, such as through culverts under roadways. Where such connections existed, the mapped inundated areas were retained in their respective flood maps; otherwise, the disconnected inundation areas were deleted. The flood-inundation areas were superimposed on high-resolution, georeferenced aerial photographs of the study area. Bridge surfaces are not shown as being inundated until a flood stage is reached that either intersects the lowest structural chord of the bridge or completely inundates one or both approaches to the bridge. Estimates of water depths can be determined from the depth-grid data that are included with the flood-inundation maps on the USGS mapping application described in the following section, “Flood-Inundation Map Delivery.”

12 Flood-Inundation Maps for Grand River, Red Cedar River and Sycamore Creek near Lansing, Michigan

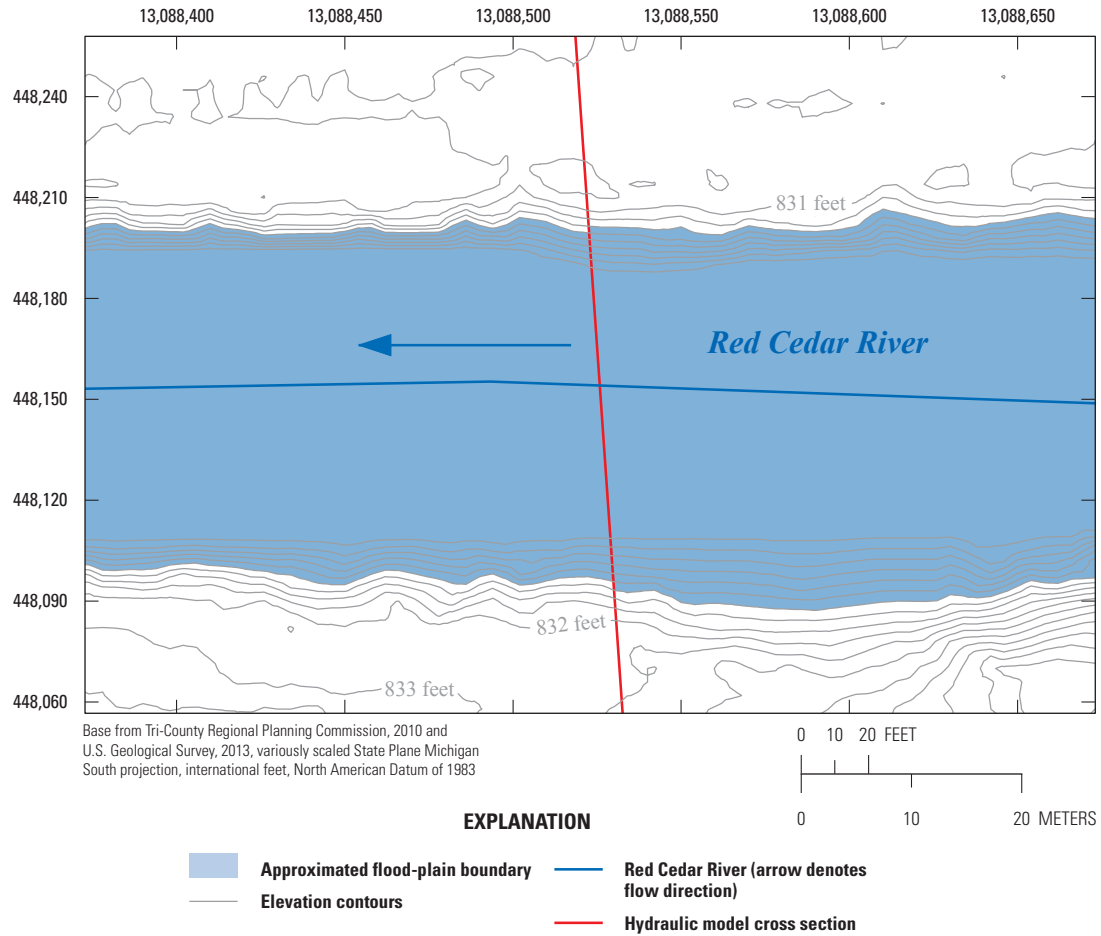
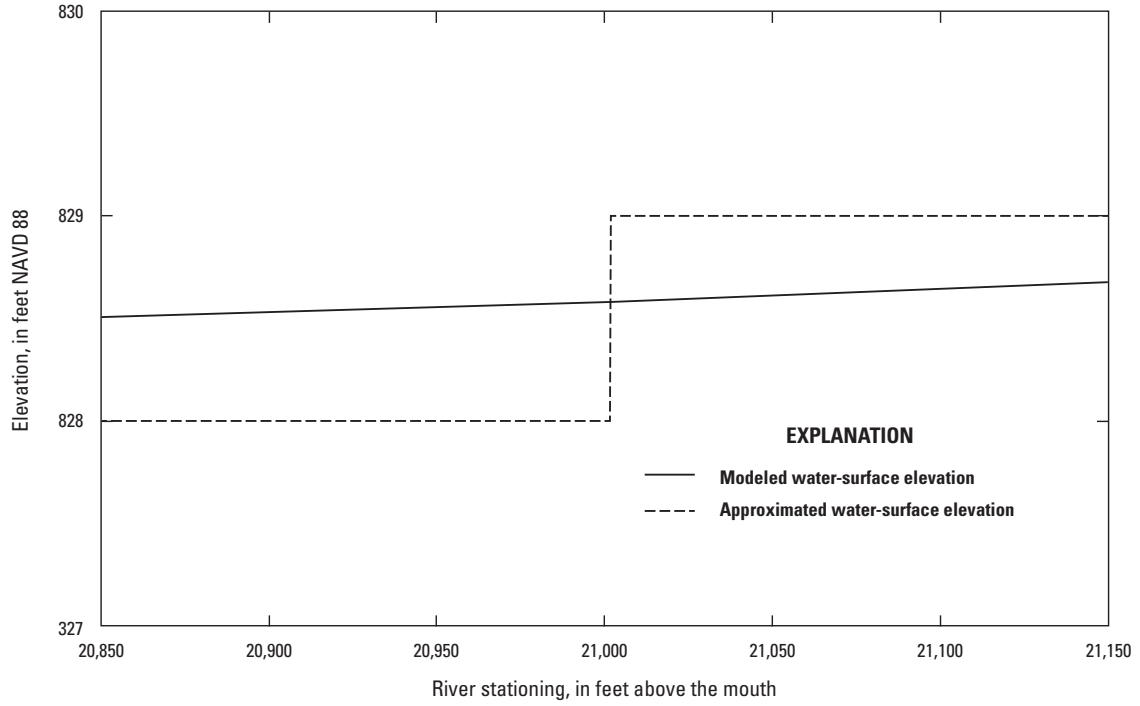


Figure 5. Modeled and approximated water-surface profile for Red Cedar River.

Flood-Inundation Map Delivery

A Flood Inundation Mapping Science Web site (U.S. Geological Survey, 2015e) was established to deliver USGS flood-inundation study information to the public. The 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 each of the three streamgages. A link on this Web site connects to the USGS National Water Information System (U.S. Geological Survey, 2015a, b, c), which presents the current stage and streamflow at each of the USGS streamgages to which the inundation maps are referenced. A second link connects to the NWS Advanced Hydrologic Prediction Service (AHPS) site (National Weather Service, 2015a, b, c) so that the user can obtain applicable information on forecasted peak. The estimated flood-inundation maps are displayed in sufficient detail 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. A shaded building should not be interpreted to mean that the structure is completely submerged but 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 floodproofing measures had been implemented.

Disclaimer for Flood-Inundation Maps

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

Uncertainties and Limitations Regarding Use of Flood-Inundation Maps

Although the flood-inundation maps represent the boundaries of inundated areas with a distinct line, some uncertainty is associated with these maps. The flood boundaries shown were estimated on the basis of water stages and streamflows at selected USGS streamgages. Water-surface elevations along the stream reaches were estimated by steady-state hydraulic modeling, assuming unobstructed flow, and using streamflows and hydrologic conditions anticipated at the USGS streamgages. The hydraulic model reflects the land-cover characteristics and any bridge, dam, levee, or other hydraulic structures existing as of January 2015. Unique meteorological factors (timing and distribution of precipitation) may cause actual streamflows along the modeled reach to vary from those

assumed during a flood, which may lead to deviations in the water-surface elevations and inundation boundaries shown. Additional areas may be flooded due to unanticipated conditions such as changes in the streambed elevation or roughness, backwater into major tributaries along a main stem river, or backwater from localized debris or ice jams. The accuracy of the floodwater extent portrayed on these maps will vary with the accuracy of the digital elevation model used to simulate the land surface.

If this series of flood-inundation maps will be used in conjunction with National Weather Service (NWS) river forecasts, the user should be aware of additional uncertainties that may be inherent or factored into NWS forecast procedures. The NWS uses forecast models to estimate the quantity and timing of water flowing through selected stream reaches in the United States. These forecast models (1) estimate the amount of runoff generated by precipitation and snowmelt, (2) simulate the movement of floodwater as it proceeds downstream, and (3) predict the flow and stage (and water-surface elevation) for the stream at a given location (AHPS forecast point) throughout the forecast period (every 6 hours and 3 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. Additional uncertainties and limitations pertinent to this study are described elsewhere in this report.

The hydraulic modeling and subsequent mapping of flood-plain boundaries assumed coincident flood peaks for the three streams studied. Actual flood-peak timing is dependent upon factors not limited to drainage-area size, slope, storage, and precipitation patterns. Coincident flood-peak timings were chosen to represent more conservative flooding scenarios. If the peak flood timing of the three streams is not coincident, the actual flooding boundaries may be different than those represented in this study.

Summary

The U.S. Geological Survey (USGS), in cooperation with the City of Lansing, Michigan, and U.S. Army Corps of Engineers, developed a series of digital flood-inundation maps showing estimates of the areal extent and depth of flooding corresponding to selected water levels (stages) at three USGS streamgages: Grand River at Lansing, MI (04113000), Red Cedar River at East Lansing, MI (04112500), and Sycamore Creek at Holt Road near Holt, MI (04112850). Altogether, the mapped areas include 19.7 stream miles. The U.S. Army Corps of Engineers’ HEC–RAS and HEC–GeoRAS programs were used to compute water-surface profiles and to help 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 each streamgage and to water-level data measured with pressure transducers during a runoff event in May 2014. The model was used to compute water-surface profiles for flood stages from nearly Action Stage to above Major Flood Stage, as reported

by the National Weather Service. The computed water-surface profiles were then used in combination with a digital elevation model (DEM), derived from light detection and ranging (lidar) data to delineate estimated flood-inundation areas and depth grids. These flood-inundation areas were superimposed 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 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 streamgages, and forecasted flood stage data from the National Weather Service Advanced Hydrologic Prediction Service can help emergency planners and the public make more informed decisions about flood risk.

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Appendix 1

Appendix 1

Modeled stage combinations for Grand River, Red Cedar River, and Sycamore Creek.

16 Flood-Inundation Maps for Grand River, Red Cedar River and Sycamore Creek near Lansing, Michigan

Appendix 1. Modeled stage combinations for Grand River, Red Cedar River, and Sycamore Creek.

[Combinations (total of 305) were generated by holding stage constant for two of the three streams and varying stage for the third by 1-foot increments for the range of stages selected for this study]

Combination	Grand River stage	Red Cedar stage	Sycamore Creek stage
1	13	8	6
2	13	8	7
3	13	8	8
4	13	8	9
5	13	8	10
6	13	9	6
7	13	9	7
8	13	9	8
9	13	9	9
10	13	9	10
11	13	10	6
12	13	10	7
13	13	10	8
14	13	10	9
15	13	10	10
16	13	11	6
17	13	11	7
18	13	11	8
19	14	8	6
20	14	8	7
21	14	8	8
22	14	8	9
23	14	8	10
24	14	9	6
25	14	9	7
26	14	9	8
27	14	9	9
28	14	9	10
29	14	10	6
30	14	10	7
31	14	10	8
32	14	10	9
33	14	10	10
34	14	10	11
35	14	11	6
36	14	11	7
37	14	11	8
38	14	11	9
39	14	11	10
40	14	12	6

Appendix 1. Modeled stage combinations for Grand River, Red Cedar River, and Sycamore Creek.—Continued

[Combinations (total of 305) were generated by holding stage constant for two of the three streams and varying stage for the third by 1-foot increments for the range of stages selected for this study]

Combination	Grand River stage	Red Cedar stage	Sycamore Creek stage
41	14	12	7
42	14	12	8
43	15	8	6
44	15	8	7
45	15	8	8
46	15	8	9
47	15	8	10
48	15	9	6
49	15	9	7
50	15	9	8
51	15	9	9
52	15	9	10
53	15	10	6
54	15	10	7
55	15	10	8
56	15	10	9
57	15	10	10
58	15	10	11
59	15	11	6
60	15	11	7
61	15	11	8
62	15	11	9
63	15	11	10
64	15	11	11
65	15	12	6
66	15	12	7
67	15	12	8
68	15	12	9
69	15	12	10
70	15	13	6
71	15	13	7
72	15	13	8
73	16	8	6
74	16	8	7
75	16	8	8
76	16	8	9
77	16	8	10
78	16	9	6
79	16	9	7
80	16	9	8
81	16	9	9

18 Flood-Inundation Maps for Grand River, Red Cedar River and Sycamore Creek near Lansing, Michigan

Appendix 1. Modeled stage combinations for Grand River, Red Cedar River, and Sycamore Creek.—Continued

[Combinations (total of 305) were generated by holding stage constant for two of the three streams and varying stage for the third by 1-foot increments for the range of stages selected for this study]

Combination	Grand River stage	Red Cedar stage	Sycamore Creek stage
82	16	9	10
83	16	10	6
84	16	10	7
85	16	10	8
86	16	10	9
87	16	10	10
88	16	10	11
89	16	11	6
90	16	11	7
91	16	11	8
92	16	11	9
93	16	11	10
94	16	11	11
95	16	12	6
96	16	12	7
97	16	12	8
98	16	12	9
99	16	12	10
100	16	12	11
101	16	13	6
102	16	13	7
103	16	13	8
104	16	13	9
105	16	13	10
106	16	14	6
107	16	14	7
108	17	8	6
109	17	8	7
110	17	8	8
111	17	8	9
112	17	8	10
113	17	9	6
114	17	9	7
115	17	9	8
116	17	9	9
117	17	9	10
118	17	10	6
119	17	10	7
120	17	10	8
121	17	10	9

Appendix 1. Modeled stage combinations for Grand River, Red Cedar River, and Sycamore Creek.—Continued

[Combinations (total of 305) were generated by holding stage constant for two of the three streams and varying stage for the third by 1-foot increments for the range of stages selected for this study]

Combination	Grand River stage	Red Cedar stage	Sycamore Creek stage
122	17	10	10
123	17	10	11
124	17	11	6
125	17	11	7
126	17	11	8
127	17	11	9
128	17	11	10
129	17	11	11
130	17	12	6
131	17	12	7
132	17	12	8
133	17	12	9
134	17	12	10
135	17	12	11
136	17	13	6
137	17	13	7
138	17	13	8
139	17	13	9
140	17	13	10
141	17	13	11
142	17	14	6
143	17	14	7
144	17	14	8
145	17	14	9
146	18	8	6
147	18	8	7
148	18	8	8
149	18	8	9
150	18	8	10
151	18	9	6
152	18	9	7
153	18	9	8
154	18	9	9
155	18	9	10
156	18	10	6
157	18	10	7
158	18	10	8
159	18	10	9
160	18	10	10
161	18	10	11

20 Flood-Inundation Maps for Grand River, Red Cedar River and Sycamore Creek near Lansing, Michigan

Appendix 1. Modeled stage combinations for Grand River, Red Cedar River, and Sycamore Creek.—Continued

[Combinations (total of 305) were generated by holding stage constant for two of the three streams and varying stage for the third by 1-foot increments for the range of stages selected for this study]

Combination	Grand River stage	Red Cedar stage	Sycamore Creek stage
162	18	11	6
163	18	11	7
164	18	11	8
165	18	11	9
166	18	11	10
167	18	11	11
168	18	12	6
169	18	12	7
170	18	12	8
171	18	12	9
172	18	12	10
173	18	12	11
174	18	13	6
175	18	13	7
176	18	13	8
177	18	13	9
178	18	13	10
179	18	13	11
180	18	14	6
181	18	14	7
182	18	14	8
183	18	14	9
184	18	14	10
185	18	14	11
186	19	8	6
187	19	8	7
188	19	8	8
189	19	8	9
190	19	8	10
191	19	9	6
192	19	9	7
193	19	9	8
194	19	9	9
195	19	9	10
196	19	10	6
197	19	10	7
198	19	10	8
199	19	10	9
200	19	10	10
201	19	10	11

Appendix 1. Modeled stage combinations for Grand River, Red Cedar River, and Sycamore Creek.—Continued

[Combinations (total of 305) were generated by holding stage constant for two of the three streams and varying stage for the third by 1-foot increments for the range of stages selected for this study]

Combination	Grand River stage	Red Cedar stage	Sycamore Creek stage
202	19	11	6
203	19	11	7
204	19	11	8
205	19	11	9
206	19	11	10
207	19	11	11
208	19	12	6
209	19	12	7
210	19	12	8
211	19	12	9
212	19	12	10
213	19	12	11
214	19	13	6
215	19	13	7
216	19	13	8
217	19	13	9
218	19	13	10
219	19	13	11
220	19	14	6
221	19	14	7
222	19	14	8
223	19	14	9
224	19	14	10
225	19	14	11
226	20	8	6
227	20	8	7
228	20	8	8
229	20	8	9
230	20	8	10
231	20	9	6
232	20	9	7
233	20	9	8
234	20	9	9
235	20	9	10
236	20	10	6
237	20	10	7
238	20	10	8
239	20	10	9
240	20	10	10
241	20	10	11

Appendix 1. Modeled stage combinations for Grand River, Red Cedar River, and Sycamore Creek.—Continued

[Combinations (total of 305) were generated by holding stage constant for two of the three streams and varying stage for the third by 1-foot increments for the range of stages selected for this study]

Combination	Grand River stage	Red Cedar stage	Sycamore Creek stage
242	20	11	6
243	20	11	7
244	20	11	8
245	20	11	9
246	20	11	10
247	20	11	11
249	20	12	7
250	20	12	8
251	20	12	9
252	20	12	10
253	20	12	11
254	20	13	6
255	20	13	7
256	20	13	8
257	20	13	9
258	20	13	10
259	20	13	11
260	20	14	6
261	20	14	7
262	20	14	8
263	20	14	9
264	20	14	10
265	20	14	11
266	21	8	6
267	21	8	7
268	21	8	8
269	21	8	9
270	21	8	10
271	21	9	6
272	21	9	7
273	21	9	8
274	21	9	9
275	21	9	10
276	21	10	6
277	21	10	7
278	21	10	8
279	21	10	9
280	21	10	10
281	21	10	11
282	21	11	6

Appendix 1. Modeled stage combinations for Grand River, Red Cedar River, and Sycamore Creek.—Continued

[Combinations (total of 305) were generated by holding stage constant for two of the three streams and varying stage for the third by 1-foot increments for the range of stages selected for this study]

Combination	Grand River stage	Red Cedar stage	Sycamore Creek stage
283	21	11	7
284	21	11	8
285	21	11	9
286	21	11	10
287	21	11	11
288	21	12	6
289	21	12	7
290	21	12	8
291	21	12	9
292	21	12	10
293	21	12	11
294	21	13	6
295	21	13	7
296	21	13	8
297	21	13	9
298	21	13	10
299	21	13	11
300	21	14	6
301	21	14	7
302	21	14	8
303	21	14	9
304	21	14	10
305	21	14	11

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