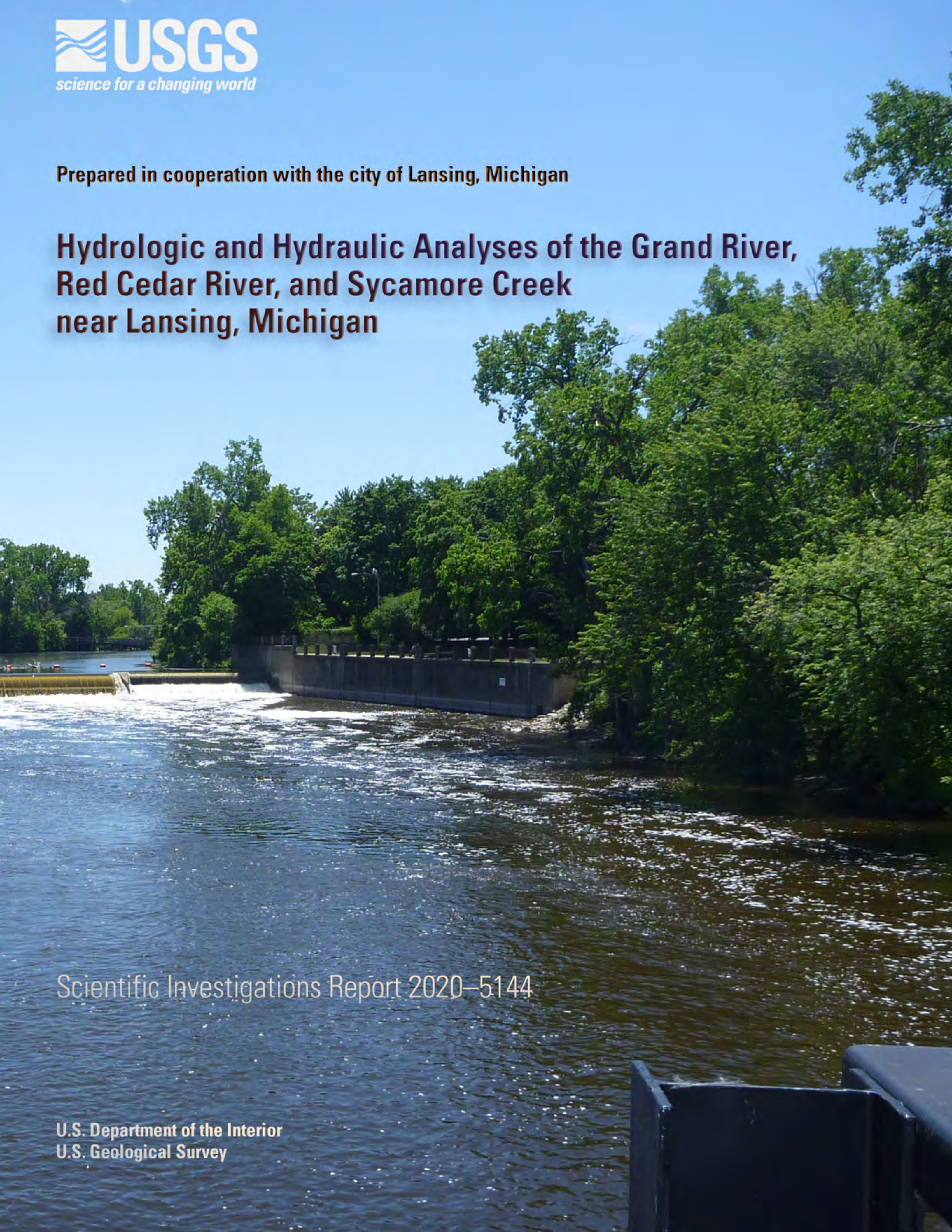
Prepared in cooperation with the city of Lansing, Michigan

Hydrologic and Hydraulic Analyses of the Grand River, Red Cedar River, and Sycamore Creek near Lansing, Michigan



Scientific Investigations Report 2020–5144

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

Cover. View from West Grand River Avenue looking upstream at the North Lansing Dam of the Grand River in Lansing, Michigan. (Photograph by U.S. Geological Survey, June 2013.)

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By Matthew T. Whitehead and Chad J. Ostheimer

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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)

Datum

Vertical coordinate information is referenced to North American Vertical Datum of 1988 (NAVD 88).

Abbreviations

AEP	annual exceedance probability
DEM	digital elevation model
FEMA	Federal Emergency Management Agency
FIS	Flood Insurance Study
GNSS	Global Navigation Satellite System
HEC–GeoRAS	Hydrologic Engineering Center’s Geospatial River Analysis System
HEC–RAS	Hydrologic Engineering Center’s River Analysis System
lidar	light detection and ranging
PILFS	potentially influential low outliers
USGS	U.S. Geological Survey

Hydrologic and Hydraulic Analyses of the Grand River, Red Cedar River, and Sycamore Creek near Lansing, Michigan

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Abstract

The U.S. Geological Survey (USGS) completed hydrologic and hydraulic analyses for selected reaches of the Grand River, Red Cedar River, and Sycamore Creek near Lansing, Michigan, in cooperation with the city of Lansing. The study comprised a 3.1-mile reach of the Grand River, a 30.3-mile reach of the Red Cedar River, and a 12.0-mile reach of Sycamore Creek. The information produced from the study can be used to update and expand an existing Federal Emergency Management Agency Flood Insurance Study for Ingham County, Mich.

Historical streamflow data from USGS streamgages on Grand River at Lansing, Mich. (station number 04113000); Red Cedar River at East Lansing, Mich. (station number 04112500); Red Cedar River near Williamston, Mich. (station number 04111379); and Sycamore Creek at Holt Road near Holt, Mich. (station number 04112850) were used to estimate instantaneous peak streamflows for floods with 10-, 4-, 2-, 1-, and 0.2-percent annual exceedance probabilities (AEPs) and a “1-percent plus” AEP.

The Hydrologic Engineering Center’s River Analysis System step-backwater model was used to determine water-surface elevation profiles for the 10-, 4-, 2-, 1-, and 0.2-percent AEP floods, the 1-percent plus AEP flood, and a regulatory floodway for each stream reach. The hydraulic models were calibrated based on stage-streamflow ratings at USGS streamgages. Flood-inundation boundaries for the 1- and 0.2-percent annual exceedance probability floods and regulatory floodway were created for each stream.

Introduction

The city of Lansing, in south central Michigan, is predominately in the northwest corner of Ingham County; however, a small part of the city extends into Eaton County to the west (fig. 1). The last flood in Lansing that equaled or exceeded the 1-percent annual exceedance probability (AEP) flood (also referred to as a “100-year flood”) occurred in 1904 (City of Lansing, 2020). The U.S. Geological Survey (USGS) streamgage on the Grand River at Lansing, Mich. (station number 04113000), hereafter referred to as the Lansing streamgage, recorded a stage of 18.60 feet (ft) on March 26, 1904 (USGS, 2020a). During the same flooding event, the USGS streamgage on Red Cedar River at East Lansing, Mich. (station number 04112500), hereafter referred to as the East Lansing streamgage, recorded a peak stage of 13.40 ft on March 24, 1904 (USGS, 2020b). The National Weather Service has designated 15.0 ft and 13.0 ft as “major flood” stages for the Lansing and East Lansing streamgages, respectively (National Weather Service, 2020b, d).

Government officials, emergency responders, and the public have relied on several information sources to make decisions on how to best alert the public to potential flooding to mitigate flood damages. One source of information is the Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) for Ingham County, Mich., dated August 16, 2011 (FEMA, 2011). However, for the Grand River, Red Cedar River, and Sycamore Creek, the 2011 FIS is a republication of hydrologic and hydraulic information last updated in 1978. A second source of information is data from four USGS streamgages (table 1) for which current stages (USGS, 2020a–d) and historical stages and streamflows (USGS, 2020e), including annual peak streamflows, can be obtained.

A third source of flood-related information is the National Weather Service Advanced Hydrologic Prediction Service web pages, which display observed and forecast stage data for the USGS streamgage Red Cedar River near Williamston, Mich. (station number 04111379; hereafter referred to as the Williamston streamgage); the East Lansing streamgage; the USGS streamgage Sycamore Creek at Holt Road near Holt, Mich. (station number 04112850; hereafter referred to as the Holt streamgage); and the Lansing streamgage (National Weather Service, 2020a–d). A fourth information source is the Flood Inundation Mapping study report (Whitehead and Ostheimer, 2015) that shows flood-inundation boundaries

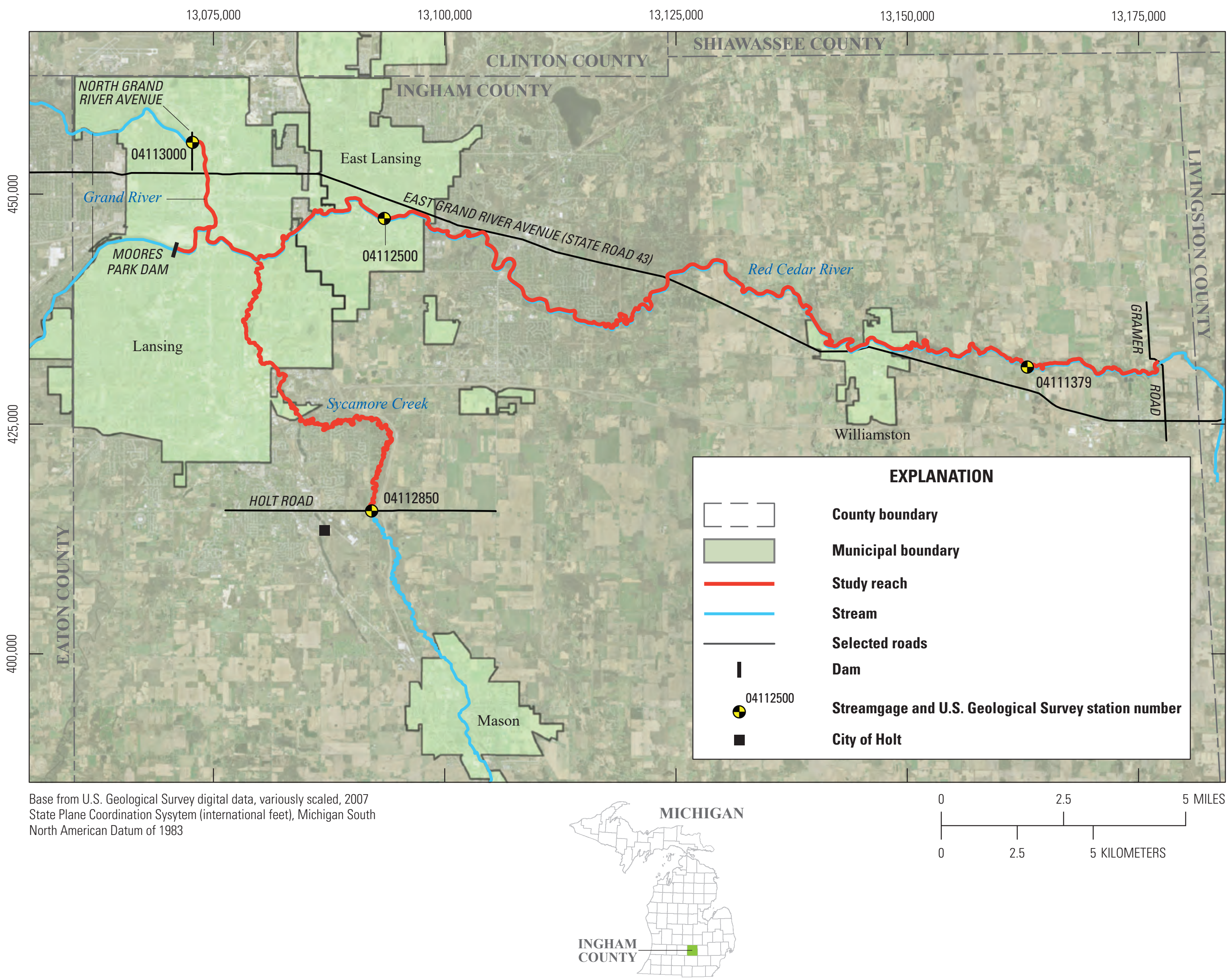

Figure 1. Location of study reaches, dam, selected roads, and U.S. Geological Survey streamgages.

Table 1. U.S. Geological Survey streamgage information for selected streams in Ingham County, Michigan.

[Locations of streamgages are shown in figure 1. USGS, U.S. Geological Survey; current, 2020; NAVD 88, North American Vertical Datum of 1988; MI, Michigan; °, degree; ′, minute; ″, second; M/DD/YYYY, M, month; DD, day; YYYY, year]

Site name	USGS station number	Drainage area (square miles)	Latitude	Longitude	Period of record	Date of maximum stage	Maximum stage (foot); elevation (NAVD88)
Grand River at Lansing, MI	04113000	1,230	42°45′02″	84°33′19″	1901–current	3/26/1904	18.60; 823.52
Sycamore Creek at Holt Road near Holt, MI	04112850	80.6	42°38′25″	84°28′58″	1975–current	4/19/1975	10.00; 854.89
Red Cedar River at East Lansing, MI	04112500	355	42°43′38″	84°28′41″	1902–current	3/24/1904	13.40; 837.36
Red Cedar River near Williamston, MI	04111379	163	42°40′59″	84°13′09″	1975–current	4/19/1975	10.41; 869.19

for selected stages on the Grand River, Red Cedar River, and Sycamore Creek. This study used and extended the hydraulic models developed for the 2015 Flood Inundation Mapping study.

Purpose and Scope

The purpose of this report is to describe the methods and results of hydrologic and hydraulic analyses for selected reaches of the Grand River, Red Cedar River, and Sycamore Creek (fig. 1). The analyses include (1) estimation of flood-peak streamflows corresponding to floods with AEPs of 10-, 4-, 2-, 1-, and 0.2-percent and the 1-percent plus AEP flood; (2) determination of water-surface elevation profiles associated with the AEPs and a regulatory floodway; and (3) delineation of floodplain boundaries associated with the 1- and 0.2-percent AEPs and a regulatory floodway. The 1-percent plus AEP flood is defined by FEMA as a flood elevation determined with streamflows equal to the sum of the regression estimates for the 1-percent AEP floods plus the average predictive error for the regression equation or as the streamflow derived by using the upper 84-percent confidence limit as calculated in the streamgage analysis for the 1-percent AEP flood (FEMA, 2019, page 10). A regulatory floodway (FEMA, 2020) is defined as the channel of a river or other watercourse and the adjacent land areas that must be reserved to discharge the 1-percent AEP flood without increasing the water-surface elevation more than a designated height.

Study Area Description

The estimated 2018 population of the city of Lansing, Mich., was about 117,000 (U.S. Census Bureau, 2020), making it the most populous city within Ingham County. Several large rivers flow through Lansing. The Grand River flows in a northerly direction (fig. 1) through downtown Lansing. Red Cedar River flows from east to west and joins the Grand River within the city limits of Lansing. Sycamore Creek, a tributary to Red Cedar River, flows in a northerly direction entering the city limits from the southeast. The confluence of Sycamore Creek with Red Cedar River is about 1.5 miles upstream (eastward) from where Red Cedar River joins the Grand River. The study reach of the Grand River has adjacent land cover that is urban, whereas the study reaches for both Red Cedar River and Sycamore Creek have a mix of rural and urban land covers.

Previous Studies

The effective FEMA FIS for Ingham County, Mich. (as of June 2020), was published on August 16, 2011 (FEMA, 2011); however, the hydrologic and hydraulic analyses for the Grand River, Red Cedar River, and Sycamore Creek on which that FIS was based were completed in 1978. An additional 45 years of streamflow data for the Grand River and Red Cedar River, and an additional 10 years of streamflow data for Sycamore Creek, are available on which to base estimates of flood magnitudes. Furthermore, since 1978, there have been changes to some bridges, including the complete removal of one bridge over Red Cedar River that the current effective FEMA study does not reflect.

Study Approach

Study tasks include (1) collection of topographic and bathymetric data for selected cross sections and geometric data for dams and bridges along the study reaches, (2) estimation of peak streamflows with selected AEPs using streamgage data and Bulletin 17C (England and others, 2019) methods,

Table 2. Selected characteristics of peak-streamflow records used in the determination of streamflow estimates for the Grand River, Red Cedar River, and Sycamore Creek near Lansing, Michigan.

[MI, Michigan]

Streamgage name and station number	Number of peaks in record	Number of peaks used in analyses	Beginning year	Ending year
Grand River at Lansing, MI (04113000)	119	115	1901	2019
Red Cedar River at East Lansing, MI (04112500)	111	111	1903	2019
Red Cedar River near Williamston, MI (04111379)	32	32	1975	2019
Sycamore Creek at Holt Road near Holt, MI (04112850)	12	12	1975	2016

(3) estimation of energy-loss factors (such as roughness coefficients) for the stream channel and floodplain, (4) computation of flood profiles and a regulatory floodway with the U.S. Army Corps of Engineers Hydrologic Engineering Center's River Analysis System (HEC–RAS) computer program (U.S. Army Corps of Engineers, 2016), and (5) development of digital flood-inundation boundaries aided by the Hydrologic Engineering Center's Geospatial River Analysis System (HEC–GeoRAS) computer program (U.S. Army Corps of Engineers, 2009) coupled with a geographic information system.

Hydrologic Analyses

Four streamgages are within the study reaches (fig. 1; table 1), and observed annual peak-streamflow data from the streamgages were used to estimate the 10-, 4-, 2-, 1-, and 0.2-percent and 1-percent plus AEP streamflows using techniques outlined in "Guidelines for Determining Flood Flow Frequency—Bulletin 17C" (England and others, 2019). The multiple Grubbs-Beck test (Cohn and others, 2013) was used to identify and screen out potentially influential low outliers (PILFS), and the expected moments algorithm (Cohn and others, 1997) was used to compute the flood-frequency estimates. Two PILFS were identified in the record for the Red Cedar River at East Lansing, Mich. (04112500). Weighted skews were computed from at-site skews and a regional skew factor of 0.086 with a mean square error of 0.13 (Veilleux and Wagner, 2019). In general, the lower and upper perception thresholds were set to 0 and infinity, respectively, except for years with missing peak-streamflow observations, which were both set to infinity. The PILFS identified in the record for the East Lansing streamgage resulted in its lower perception threshold for observed peaks to be set to 785 cubic feet per second. Mann-Kendall tests (Mann, 1945), which measure the strength of the monotonic relation between annual peak streamflows and the years in which they occurred, were done to screen for potential trend in annual peak streamflows. Only the East Lansing streamgage had a statistically significant (alpha=0.05) indicator of trend. The tau statistic was -0.141 (p-value 0.028) indicating that annual peak streamflows have been decreasing during the period of record with a median slope of -6.25 cubic feet per second per year. Despite this indicator of potential trend, the peak-streamflow record for the East Lansing streamgage was treated as stationary when computing its flood-frequency characteristics. For the Grand River analyses, inspection of the peak streamflow hydrographs indicated a potential effect of regulation for four peaks (likely caused by the Moores Park Dam—just upstream from the study reach). As a result, the four peaks were not included in the analyses. For an ungaged location, peak streamflow was estimated by multiplying the streamgage location peak-streamflow estimate by the drainage area ratio of the ungaged location to the gaged location. Table 2 lists some general characteristics of the data used in the flood-frequency analyses, with flood-frequency estimates listed in table 3.

Table 3. Magnitude estimates for floods with annual exceedance probabilities of 10-, 4-, 2-, 1-, and 0.2-percent and 1-percent plus for the selected locations on streams near Lansing, Michigan.

[DA, drainage area; mi², square miles; ft³/s, cubic foot per second; %, percent; °, degree; ′, minute; ″, second; USGS, U.S. Geological Survey]

Location description	Latitude	Longitude	DA (mi²)	Annual exceedance probability flood-peak streamflows (ft³/s)					
				10%	4%	2%	1%	0.20%	1% plus
Grand River									
Above Red Cedar River	42°43′29″	84°32′52″	771	6,090	7,710	9,030	10,400	13,900	11,800
At USGS streamgage (04113000)	42°45′02″	84°33′19″	1,230	9,720	12,300	14,400	16,600	22,200	18,900
Red Cedar River									
At Gramer Road	42°41′05″	84°10′00″	133	1,170	1,490	1,730	2,000	2,690	2,550
Below Wolf Creek	42°40′58″	84°11′08″	151	1,330	1,690	1,960	2,270	3,060	2,890
At USGS streamgage (04111379)	42°40′59″	84°13′09″	163	1,440	1,820	2,120	2,450	3,300	3,120
Below Squaw Creek	42°41′25″	84°14′30″	175	1,550	1,950	2,280	2,630	3,540	3,350
Below Deer Creek	42°41′17″	84°17′25″	265	2,750	3,540	4,170	4,840	6,600	5,590
Below West Grand River Avenue (State Route 43)	42°42′34″	84°21′50″	292	3,030	3,900	4,590	5,330	7,270	6,150
At USGS streamgage (04112500)	42°43′38″	84°28′41″	355	3,690	4,740	5,580	6,480	8,840	7,490
Below Sycamore Creek	42°42′49″	84°31′38″	459	4,770	6,130	7,210	8,380	11,400	9,680
Sycamore Creek									
At USGS streamgage (04112850)	42°38′25″	84°28′58″	80.6	1,170	1,470	1,700	1,950	2,580	2,820
Below unnamed tributary from the west	42°40′36″	84°31′13″	88.1	1,280	1,610	1,860	2,130	2,820	3,080

Hydraulic Analyses

Flood profiles were computed with HEC–RAS, version 5.0.3 (U.S. Army Corps of Engineers, 2016). HEC–RAS can perform one and two-dimensional hydraulic calculations for a network of channels under steady-state or unsteady-state streamflow conditions. All profiles in this study were computed using one-dimensional steady-state streamflow calculations. Inputs for steady-state streamflow calculations include streamflow regime, boundary conditions, and streamflow estimates. A subcritical streamflow regime was assumed for all calculations.

Roughness Estimates

Energy losses exerted by a channel on flowing water must be estimated when doing one-dimensional hydraulic analyses. A part of the energy losses can be quantified by Manning's roughness coefficient ("*n*"), a measure of the effective resistance water experiences when passing over land and channel features due to a variety of factors. Initial (precalibration) *n* values were selected on the basis of field observations and high-resolution aerial photographs. As part of the model-calibration process, *n* values were adjusted from initial estimates until the differences between simulated and rating-based water-surface elevations at each streamgage were minimized for the given design streamflows. For all reaches studied, the final minimum and maximum n values ranged from 0.040 to 0.054 for the main channel and from 0.036 to 0.100 for the overbank areas (table 4).

Field Surveys

The USGS used both differential Global Navigation Satellite System (GNSS) surveys and differential-leveling surveys (“conventional” surveys) for this study. Differential GNSS surveys were done to establish a horizontal and vertical control network at selected locations along each of the streams studied. Conventional surveys were done to obtain stream and hydraulic-structure geometry. All conventional survey data collected met horizontal and vertical third-order accuracy criteria (Federal Geodetic Control Committee, 1984). Differential GNSS surveys were done using level III real-time GNSS surveying techniques (Rydlund and Densmore, 2012). Elevations determined using a differential GNSS at nine benchmark locations had a root-mean-square error of 0.11 ft compared to National Geodetic Survey published elevations.

USGS field crews surveyed 284 channel cross sections (table 4) and 68 hydraulic structures. The cross sections were surveyed to provide ground elevations below stream-water surfaces that could not be obtained from light detection and ranging (lidar). The structures were surveyed to obtain geometrical data that can affect water-surface elevations along the streams during floods.

Topographic and Bathymetric Data

Above water cross-section elevation data were obtained from a 4- by 4-ft-resolution digital elevation model (DEM) that was provided to the USGS by Tri-County Regional Planning Commission (Whitehead and Ostheimer, 2015). The DEM was derived from lidar data collected during March 2010. The original lidar data have a horizontal resolution of 3.8 ft and a vertical accuracy of plus or minus 0.49 ft at a 95-percent confidence level for the “open terrain” land-cover category (root-mean-square error of 0.5 ft) (Federal Geographic Data Committee, 1998). With that resolution and accuracy, the lidar data support production of 2-ft contours (Dewberry, 2012). The USGS created 2-ft contour lines from the DEM data for use in floodplain-boundary delineation using ArcGIS.

Using HEC–GeoRAS, land-surface elevation data were extracted from the DEM for 854 cross sections (table 4) for this study. DEM-derived cross section data were collocated with the locations of the 284 in-channel field-surveyed cross sections where available. In those cases, in-channel data were directly merged with the DEM data. The bathymetry for the DEM-derived cross section data that did not have surveyed in-channel cross sections were estimated (accounting for channel bed elevation and bottom of channel width) by interpolating between the closest upstream and downstream field-surveyed cross sections.

Hydraulic Modeling

Hydraulic baseline distances for the Grand River are referenced to the North Grand River Avenue bridge, near the Lansing streamgage (fig. 1). The upstream limit is the Moores Park Dam: a total reach length of 3.1 miles. For Red Cedar River, hydraulic baseline distances are referenced from the mouth (confluence with the Grand River), and the upstream limit is the Gramer Road bridge, which is about one stream mile west of the Ingham/Livingston county line. The total stream length simulated for Red Cedar River is 30.3 miles. For Sycamore Creek, hydraulic baseline distances are referenced from the mouth (the confluence with Red Cedar River), and the upstream limit is Holt Road, the location of Holt streamgage (fig. 1). The total simulated length of Sycamore Creek is 12.0 miles (table 4).

Table 4. Selected model-related characteristics of study reaches on the Grand River, Red Cedar River, and Sycamore Creek near Lansing, Michigan.

[n, Manning’s roughness coefficient]

Stream name	Baseline reference location[1]	Study reach length (mile)	Number of surveyed cross sections	Number of cross sections derived from digital elevation model	Number of hydraulic structures	Downstream boundary condition	Channel n value range	Overbank n value range
Grand River	North Grand River Avenue	3.1	60	23	15	Known	0.040–0.042	0.042–0.062
Red Cedar River	Mouth	30.3	157	384	36	Slope	0.040–0.054	0.036–0.090
Sycamore Creek	Mouth	12	67	163	17	Slope	0.042–0.046	0.042–0.100

[1]Location from which the river stationing is measured upstream, in feet.

The downstream boundary conditions used in HEC–RAS for the Grand River were known water-surface elevations. A straight-line extrapolation/extension of the current stage-streamflow rating (rating 15) for the Lansing streamgage was used to determine some stages for the selected streamflow estimates. The rating was extended from its maximum stage of 15.50 ft to 21.34 ft. Stages were converted to North American Vertical Datum of 1988 elevations by adding the streamgage datum of 804.92 ft (USGS, 2020a).

Normal depth boundary conditions were used for Red Cedar River and Sycamore Creek. Normal depth is defined as the depth when the streamflow is uniform, steady, one-dimensional, and not affected by downstream obstructions. Streamflow is considered uniform if the energy-grade line, water surface, and channel bottom all are parallel (Chow, 1959). The friction slopes (equal to the channel slopes), for the normal depth calculations, were determined from field surveys near their corresponding downstream limits. The slopes calculated and used in the hydraulic models for Red Cedar River and Sycamore Creek are 0.00022 foot per foot (ft/ft) and 0.0015 ft/ft, respectively.

Hydraulic Modeling Calibration

For Red Cedar River and Sycamore Creek, the hydraulic models were calibrated to current (June 2020) stage-streamflow ratings at each of three streamgage locations (two on Red Cedar River and one on Sycamore Creek) by converting the stage information to North American Vertical Datum of 1988 elevations using the vertical datum of the streamgage. The stage-streamflow rating used for the East Lansing streamgage is rating number 16.1 and provides streamflow estimates for a stage as much as 11.0 ft. The stage-streamflow rating used for the Williamston streamgage is rating number 8.0 and provides streamflow estimates for a stage as much as 10.41 ft. The stage-streamflow rating used for the Holt streamgage is rating number 7.0 and provides streamflow estimates for a stage as much as 9.3 ft. Model calibration was accomplished by adjusting Manning's *n* values, ineffective flow areas, and contraction/expansion coefficients until the results of the hydraulic computations minimized the differences between the rating-based water-surface elevations and the simulated peak streamflows. For each set of stream profiles, a single set of optimized variables were used for all simulated streamflows. Absolute differences between elevations determined from the current stage-streamflow ratings and simulated water-surface elevations for the range of stages at each streamgage were less than or equal to 0.17 foot (table 5), with a root-mean-square error of 0.09 ft.

Development of Flood Profiles

The calibrated HEC–RAS models were used to develop seven flood profiles for each stream corresponding to the 10-, 4-, 2-, 1-, and 0.2-percent and 1-percent plus AEP floods and a regulatory floodway. The profiles show computed water-surface elevations as a function of distance from a reference location. Using HEC–RAS, plots can be viewed that show the minimum channel elevations at each cross section and hydraulic structure. All elevations displayed in HEC–RAS are referenced to the North American Vertical Datum of 1988.

Development of Flood-Inundation Boundaries

Flood-inundation boundaries for each stream were created in a geographic information system for three flood profiles (the 1- and 0.2-percent AEP floods and a regulatory floodway) by combining flood-profile data with digital elevation data from the lidar-derived DEM. The DEM (Whitehead and Ostheimer, 2020) has an estimated vertical accuracy of 1 ft. Initial flood-inundation boundaries were delineated for each profile with the HEC–GeoRAS software (U.S. Army Corps of Engineers, 2009). HEC–GeoRAS provides a set of procedures, tools, and utilities for processing geospatial data in ArcGIS (U.S. Army Corps of Engineers, 2009). Flood-inundation boundaries were subsequently modified in ArcMap (Environmental Systems Research Institute, 2017) to ensure the flood boundaries between simulated cross sections varied in a reasonable fashion with respect to intervening topography.

Any inundated areas that appeared disconnected from the main channel were examined to identify artificial connections with the main river, such as through culverts under roadways. Where such connections existed, the inundated areas were retained in their respective flood-boundary delineations; otherwise, the disconnected inundated areas were deleted.

Data Dissemination

All hydraulic models and data used in the creation of the flood-inundation boundaries are available as a USGS data release (Whitehead and Ostheimer, 2020) and will be submitted to FEMA for inclusion in an updated FIS for Ingham County. FEMA has the sole statutory responsibility for publishing an FIS including regulatory floodplain boundaries. As a result, all data in Whitehead and Ostheimer (2020) should be considered provisional (in terms of use as a regulatory product). Floodway data tables listing floodway characteristics and base flood water-surface elevations at simulated cross sections for each stream are presented in the appendix.

Summary

The U.S. Geological Survey, in cooperation with the city of Lansing, Michigan, updated and expanded hydraulic models for three streams to facilitate a future update to the Federal

Table 5. Calibration results of the hydraulic models to target water-surface elevations for selected streamgage locations.

[ft^3/s, cubic foot per second; ft, foot; NAVD 88, North American Vertical Datum of 1988; MI, Michigan]

Streamflow (ft^3/s)	Rating-based water-surface elevation (ft, NAVD 88)	Simulated water-surface elevation (ft, NAVD 88)	Difference in elevation (ft)
Red Cedar River at East Lansing, MI (04112500), rating number 16.1			
1,280	829.96	830.01	-0.05
1,930	830.96	831.13	-0.17
2,570	831.96	832.08	-0.12
3,230	832.96	832.96	0.00
4,040	833.96	833.93	0.03
4,400	834.37	834.33	0.04
4,930	834.96	834.82	0.14
Red Cedar River at Williamston, MI (04111379), rating number 8.0			
457	864.78	864.70	0.08
768	865.78	865.87	-0.09
1,180	866.78	866.78	0.00
1,710	867.78	867.75	0.03
2,360	868.78	868.81	-0.03
2,670	869.19	869.31	-0.12
Sycamore Creek at Holt Road near Holt, MI (04112850), rating number 7.0			
119	849.89	850.05	-0.16
184	850.89	850.76	0.13
346	851.89	851.98	-0.09
614	852.89	853.00	-0.11
1,000	853.89	853.90	-0.01

Emergency Management Agency Flood Insurance Study for Ingham County, Mich. The study comprised a 3.1-mile reach of the Grand River, a 30.3-mile reach of Red Cedar River, and a 12.0-mile reach of Sycamore Creek. Flood profiles were developed for the 10-, 4-, 2-, 1-, and 0.2-percent and 1-percent plus annual exceedance probability floods and a regulatory floodway. Provisional digital flood-inundation boundaries were developed for the 1- and 0.2-percent annual exceedance probability floods and a regulatory floodway.

The U.S. Army Corps of Engineers Hydrologic Engineering Center's River Analysis System computer program was used to compute water-surface profiles, and their Hydrologic Engineering Center's Geospatial River Analysis System computer program was used to help delineate the flood-inundation boundaries. Model inputs included cross sections derived from a digital elevation model supplemented with field surveys of open-channel cross sections and hydraulic structures, estimates of roughness values, and annual exceedance probability flood estimates determined from historical streamflow data.

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Appendix 1

Table 1.1. Floodway data table for the Grand River, Ingham County, Michigan.

[ft, foot; ft^2, square foot; ft/s, foot per second; NAVD 88, North American Vertical Datum of 1988]

Flooding source		Floodway			Base flood water-surface elevation			
Cross section	Distance[1]	Width, in ft	Section area, in ft^2	Mean velocity, in ft/s	Regulatory, in ft, NAVD 88	Without floodway, in ft, NAVD 88	With floodway, in ft, NAVD 88	Increase, in ft
A	68	280	4,094	4.1	824.3	824.3	824.3	0.0
B	1,927	260	3,526	4.7	824.8	824.8	824.8	0.0
C	2,078	209	3,751	4.4	825.4	825.4	825.5	0.1
D	2,757	361	4,714	3.5	826.6	826.6	826.6	0.0
E	3,643	292	4,353	3.8	826.8	826.8	826.9	0.1
F	4,611	758	5,049	3.3	827.1	827.1	827.2	0.1
G	5,136	460	4,816	3.5	827.3	827.3	827.4	0.1
H	5,965	400	4,467	3.7	827.5	827.5	827.6	0.1
I	7,088	260	3,774	4.4	827.8	827.8	827.9	0.1
J	7,318	185	3,206	5.2	827.9	827.9	828.0	0.1
K	8,578	385	4,607	3.6	828.5	828.5	828.6	0.1
L	8,888	360	4,817	3.5	828.7	828.7	828.7	0.0
M	10,579	445	4,321	3.8	829.1	829.1	829.2	0.1
N	11,643	430	3,580	2.9	829.5	829.5	829.6	0.1
O	13,459	260	3,388	3.1	830.1	830.1	830.1	0.0
P	14,028	210	2,961	3.5	830.2	830.2	830.3	0.1
Q	15,103	350	5,300	2.0	830.9	830.9	831.0	0.1
R	15,340	400	5,765	1.8	831.0	831.0	831.0	0.0
S	16,599	370	5,670	1.8	831.1	831.1	831.2	0.1

[1]Feet above North Grand River Avenue.

Table 1.2. Floodway data table for Red Cedar River, Ingham County, Michigan.

[ft, foot; ft²; square foot; ft/s, foot per second; NAVD 88, North American Vertical Datum of 1988]

Flooding source		Floodway			Base flood water-surface elevation			
Cross section	Distance[1]	Width, in ft	Section area, in ft^2	Mean velocity, in ft/s	Regulatory, in ft, NAVD 88	Without floodway, in ft, NAVD 88	With floodway, in ft, NAVD 88	Increase, in ft
A	478	375	3,045	2.8	[2]829.1	828.2	828.3	0.1
B	1,217	282	2,188	3.8	[2]829.1	828.4	828.5	0.1
C	2,706	135	2,307	3.6	[2]829.1	829.0	829.1	0.1
D	3,500	240	3,331	2.5	829.5	829.5	829.6	0.1
E	4,710	320	3,553	2.5	829.9	829.9	830.0	0.1
F	5,312	630	5,365	1.6	830.1	830.1	830.2	0.1
G	7,623	888	9,647	0.9	830.3	830.3	830.4	0.1
H	9,219	1,500	15,740	0.6	830.4	830.4	830.5	0.1
I	9,441	1,542	15,987	0.7	830.4	830.4	830.5	0.1
J	9,765	1,420	14,169	1.1	830.5	830.5	830.5	0.0
K	11,638	336	4,106	1.6	831.1	831.1	831.2	0.1
L	13,120	1,221	12,739	0.5	831.2	831.2	831.3	0.1
M	13,784	300	3,197	2.0	831.2	831.2	831.3	0.1
N	14,275	225	2,330	2.8	831.4	831.4	831.5	0.1
O	16,089	167	1,877	3.5	832.2	832.2	832.3	0.1
P	16,719	502	5,188	1.3	832.6	832.6	832.7	0.1
Q	18,582	1,200	9,988	0.7	832.8	832.8	832.9	0.1
R	20,139	412	3,221	2.0	832.8	832.8	832.9	0.1
S	21,531	133	1,572	4.1	833.4	833.4	833.5	0.1
T	22,109	195	1,790	3.6	834.2	834.2	834.3	0.1
U	22,489	600	4,356	1.5	834.6	834.6	834.7	0.1
V	23,170	1,000	7,165	0.9	834.8	834.8	834.9	0.1
W	25,226	800	4,896	1.3	834.8	834.8	834.9	0.1
X	25,570	719	3,946	1.6	834.9	834.9	835.0	0.1
Y	26,639	250	2,216	2.9	835.3	835.3	835.3	0.0
Z	27,291	125	1,198	5.4	835.7	835.7	835.8	0.1
AA	27,647	157	1,615	4.0	836.3	836.3	836.3	0.0
AB	28,128	143	1,541	4.2	836.6	836.6	836.7	0.1
AC	28,390	121	1,568	4.1	836.8	836.8	836.9	0.1
AD	29,812	209	2,208	2.4	837.4	837.4	837.5	0.1

Table 1.2. Floodway data table for Red Cedar River, Ingham County, Michigan.—Continued

[ft, foot; ft^2; square foot; ft/s, foot per second; NAVD 88, North American Vertical Datum of 1988]

Flooding source		Floodway			Base flood water-surface elevation			
Cross section	Distance[1]	Width, in ft	Section area, in ft^2	Mean velocity, in ft/s	Regulatory, in ft, NAVD 88	Without floodway, in ft, NAVD 88	With floodway, in ft, NAVD 88	Increase, in ft
AE	30,095	221	2,285	2.3	837.5	837.5	837.6	0.1
AF	32,656	230	2,313	2.3	838.1	838.1	838.2	0.1
AG	33,347	325	2,700	2.0	838.5	838.5	838.5	0.0
AH	35,517	410	3,433	1.6	838.9	838.9	839.0	0.1
AI	37,307	228	2,322	2.3	839.1	839.1	839.2	0.1
AJ	37,615	140	1,788	3.0	839.3	839.3	839.4	0.1
AK	41,550	771	5,321	1.0	840.0	840.0	840.1	0.1
AL	42,536	742	3,822	1.4	840.0	840.0	840.1	0.1
AM	46,006	589	3,715	1.4	840.8	840.8	840.9	0.1
AN	47,439	220	1,678	3.2	841.0	841.0	841.1	0.1
AO	47,779	262	2,233	2.4	841.7	841.7	841.7	0.0
AP	51,269	119	1,268	4.2	842.4	842.4	842.5	0.1
AQ	54,456	487	3,485	1.5	843.9	843.9	844.0	0.1
AR	56,892	260	2,287	2.3	844.6	844.6	844.7	0.1
AS	58,048	196	2,090	2.6	844.9	844.9	845.0	0.1
AT	60,554	317	2,616	2.0	845.7	845.7	845.8	0.1
AU	67,366	1,002	6,172	0.9	846.6	846.6	846.7	0.1
AV	72,069	962	5,471	1.0	846.8	846.8	846.9	0.1
AW	72,295	1,032	6,474	0.8	847.3	847.3	847.4	0.1
AX	77,704	1,070	4,943	1.1	848.2	848.2	848.3	0.1
AY	80,041	579	3,254	1.6	849.2	849.2	849.3	0.1
AZ	81,953	540	2,897	1.7	850.5	850.5	850.6	0.1
BA	88,004	412	2,859	1.7	853.1	853.1	853.1	0.0
BB	92,968	611	2,964	1.6	854.9	854.9	855.0	0.1
BC	97,751	802	3,613	1.3	856.5	856.5	856.6	0.1
BD	100,213	373	2,083	2.3	857.6	857.6	857.7	0.1
BE	101,935	541	3,303	1.5	858.3	858.3	858.4	0.1
BF	109,297	1,134	5,509	0.9	859.9	859.9	860.0	0.1
BG	114,005	1,211	6,116	0.4	861.0	861.0	861.1	0.1
BH	115,973	345	692	3.8	861.2	861.2	861.3	0.1

Table 1.2. Floodway data table for Red Cedar River, Ingham County, Michigan.—Continued

[ft, foot; ft²; square foot; ft/s, foot per second; NAVD 88, North American Vertical Datum of 1988]

Flooding source		Floodway			Base flood water-surface elevation			
Cross section	Distance[1]	Width, in ft	Section area, in ft²	Mean velocity, in ft/s	Regulatory, in ft, NAVD 88	Without floodway, in ft, NAVD 88	With floodway, in ft, NAVD 88	Increase, in ft
BI	116,833	130	1,321	2.0	862.0	862.0	862.0	0.0
BJ	119,499	99	596	4.4	862.5	862.5	862.6	0.1
BK	121,220	700	2,967	0.9	863.6	863.6	863.7	0.1
BL	127,445	760	2,705	1.0	864.2	864.2	864.2	0.0
BM	133,989	706	2,723	0.9	866.2	866.2	866.3	0.1
BN	137,197	125	945	2.6	868.2	868.2	868.3	0.1
BO	140,863	263	1,522	1.6	869.1	869.1	869.2	0.1
BP	146,300	699	2,422	0.9	870.5	870.5	870.6	0.1
BQ	150,983	174	1,002	2.3	872.7	872.7	872.8	0.1
BR	154,293	624	2,934	0.7	873.3	873.3	873.4	0.1
BS	157,303	700	2,087	1.0	873.6	873.6	873.7	0.1
BT	159,747	254	1,019	2.0	874.2	874.2	874.3	0.1

[1]Feet above mouth.

[2]Regulatory elevation of Grand River at river station 11,453 (included in this study).

Table 1.3. Floodway data table for Sycamore Creek, Ingham County, Michigan.

[ft, foot; ft^2, square feet; ft/s, foot per second; NAVD 88, North American Vertical Datum]

Flooding source		Floodway			Base flood water surface elevation			
Cross section	Distance[1]	Width, in ft	Section area, in ft^2	Mean velocity, in ft/s	Regulatory, in ft, NAVD 88	Without floodway, in ft, NAVD 88	With floodway, in ft, NAVD 88	Increase, in ft
A	668	325	794	2.7	[2]830.4	821.1	821.1	0.0
B	1,732	77	517	4.1	[2]830.4	822.6	822.6	0.0
C	1,836	81	517	4.1	[2]830.4	822.8	822.8	0.0
D	3,348	400	1,399	1.5	[2]830.4	823.7	823.8	0.1
E	4,620	650	2,034	1.1	[2]830.4	824.1	824.1	0.0
F	5,074	806	2,336	0.9	[2]830.4	824.2	824.2	0.0
G	6,602	660	1,844	1.2	[2]830.4	824.8	824.8	0.0
H	6,932	493	1,252	1.7	[2]830.4	825.0	825.1	0.1
I	8,443	725	1,639	1.3	[2]830.4	826.5	826.6	0.1
J	10,397	110	355	6.0	[2]830.4	829.0	829.0	0.0
K	11,664	300	1,435	1.5	831.3	831.3	831.4	0.1
L	13,550	90	638	3.3	832.1	832.1	832.2	0.1
M	13,717	140	913	2.3	832.5	832.5	832.5	0.0
N	14,458	800	2,741	0.9	832.8	832.8	832.9	0.1
O	14,587	825	3,919	0.6	832.9	832.9	833.0	0.1
P	15,290	200	1,117	2.0	833.0	833.0	833.0	0.0
Q	15,441	85	613	3.5	833.1	833.1	833.2	0.1
R	16,281	335	1,703	1.3	833.9	833.9	834.0	0.1
S	16,965	225	798	2.7	834.2	834.2	834.3	0.1
T	17,367	53	437	4.9	834.6	834.6	834.7	0.1
U	17,724	104	678	3.1	835.4	835.4	835.5	0.1
V	18,518	165	878	2.4	836.1	836.1	836.2	0.1
W	19,314	450	1,737	1.2	836.6	836.6	836.7	0.1
X	20,102	300	1,090	2.0	836.8	836.8	836.9	0.1
Y	21,586	260	938	2.3	837.9	837.9	837.9	0.0
Z	23,301	125	816	2.4	839.6	839.6	839.6	0.0
AA	24,617	300	1,615	1.2	840.1	840.1	840.2	0.1
AB	27,171	170	1,021	1.9	840.4	840.4	840.5	0.1
AC	28,929	500	1,960	1.0	841.1	841.1	841.2	0.1
AD	31,026	750	2,345	0.8	841.5	841.5	841.6	0.1

Table 1.3. Floodway data table for Sycamore Creek, Ingham County, Michigan.—Continued

[ft, foot; ft^2, square feet; ft/s, foot per second; NAVD 88, North American Vertical Datum]

Flooding source		Floodway			Base flood water surface elevation			
Cross section	Distance[1]	Width, in ft	Section area, in ft^2	Mean velocity, in ft/s	Regulatory, in ft, NAVD 88	Without floodway, in ft, NAVD 88	With floodway, in ft, NAVD 88	Increase, in ft
AE	32,358	125	729	2.7	842.1	842.1	842.1	0.0
AF	32,457	140	708	2.8	842.3	842.3	842.3	0.0
AG	34,437	775	2,247	0.9	843.0	843.0	843.1	0.1
AH	36,411	400	1,475	1.3	843.6	843.6	843.7	0.1
AI	41,252	675	2,274	0.9	845.2	845.2	845.3	0.1
AJ	43,256	122	792	2.5	845.9	845.9	846.0	0.1
AK	43,572	300	1,288	1.5	846.2	846.2	846.3	0.1
AL	45,567	680	2,345	0.8	846.9	846.9	847.0	0.1
AM	47,841	660	2,240	0.9	847.3	847.3	847.4	0.1
AN	50,038	600	1,605	1.7	848.0	848.0	848.1	0.1
AO	53,173	670	2,054	1.0	849.3	849.3	849.4	0.1
AP	55,013	125	685	2.9	850.1	850.1	850.2	0.1
AQ	55,119	120	693	2.8	850.3	850.3	850.4	0.1
AR	58,312	855	2,379	0.8	851.8	851.8	851.8	0.0
AS	60,648	400	1,216	1.6	853.0	853.0	853.1	0.1
AT	62,747	300	1,143	1.7	854.8	854.8	854.9	0.1
AU	63,320	56	485	4.0	855.4	855.4	855.5	0.1
AV	63,412	51	455	4.3	855.6	855.6	855.7	0.1

[1]Feet above mouth.

[2]Regulatory elevation of Red Cedar River at river station 8,209 (included in this study).

For additional information contact:

Director, USGS Ohio-Kentucky-Indiana Water Science Center
U.S. Geological Survey
6460 Busch Blvd., Suite 100
Columbus, OH 43229

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