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Prepared in cooperation with the Bad River Band of the Lake Superior Chippewa Tribe

Flood of July 2016 in Northern Wisconsin and the Bad River Reservation

Scientific Investigations Report 2017–5029

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

Front cover photograph. The Bad River at Government Road bridge near Odanah, Wisconsin, on July 12, 2016, by Naomi Tillison, Bad River Tribe Natural Resources Department.

Back cover photographs (top to bottom). Aerial view of flooding of the Kakagon River at Kakagon Road crossing with fish hatchery on the west (left) side; examples of high-water mark, mud line on stage at powwow grounds; flooded portion of Kakagon Road looking east from the fish hatchery; example of surveying high-water marks, a total station; Denomie Creek flood damage at the U.S. Highway 2 bridge (photograph from the Bad River Band of Lake Superior Chippewa Tribe).

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
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 the North American Vertical Datum of 1988 (NAVD 88).

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

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

Water year is the 12-month period of October 1 through September 30 designated by the calendar year in which it ends.

Abbreviations

AEP	annual exceedance probability
DEM	digital elevation model
GIS	geographic information system
GLONASS	Global Navigation Satellite System
GPS	global positioning system
HWM	high-water mark
lidar	light detection and ranging
NAVD 88	North American Vertical Datum of 1988
NAVSTAR	navigation satellite timing and ranging
RTK–GPS	real-time kinematic global positioning system
RTN–GPS	real-time network global position system
STN	short-term network
USGS	U.S. Geological Survey
WISCORS	Wisconsin Department of Transportation Continuously Operating Reference Stations

Flood of July 2016 in Northern Wisconsin and the Bad River Reservation

By Faith A. Fitzpatrick, Eric D. Dantoin, Naomi Tillison[1], Kara M. Watson, Robert J. Waschbusch, and James D. Blount

Abstract

Heavy rain fell across northern Wisconsin and the Bad River Reservation on July 11, 2016, as a result of several rounds of thunderstorms. The storms caused major flooding in the Bad River Basin and nearby tributaries along the south shore of Lake Superior. Rainfall totals were 8–10 inches or more and most of the rain fell in an 8-hour period. A streamgage on the Bad River near Odanah, Wisconsin, rose from 300 cubic feet per second to a record peak streamflow of 40,000 cubic feet per second in only 15 hours. Following the storms and through September 2016, personnel from the U.S. Geological Survey and Bad River Tribe Natural Resources Department recovered and documented 108 high-water marks near the Bad River Reservation. Many of these high-water marks were used to create three flood-inundation maps for the Bad River, Beartrap Creek, and Denomie Creek for the Bad River Reservation in the vicinity of the community of Odanah.

Introduction

Multiple rounds of strong to severe thunderstorms quickly hit northern Wisconsin and the Bad River Reservation (fig. 1) on Monday July 11, 2016, resulting in historic flooding in the Bad River Basin and nearby areas, including the Bad River Tribal community of Odanah, Wisconsin (National Weather Service, 2016a; fig. 2). Rainfall totals were 8–10 inches or more, most of the rain fell within an 8-hour period. Annual exceedance probabilities (AEP) for a worst-case 6-hour rainfall were less than 0.1 percent at the center of the highest rainfall (National Weather Service, 2016b). Damages resulting from flooding were estimated to be $25 million to roads and public infrastructure (Wisconsin Public Radio, 2016).

Immediately following the flood, the U.S. Geological Survey (USGS) and the Natural Resources Department of the Bad River Band of the Lake Superior Chippewa Tribe (hereafter referred to as the Bad River Tribe) began identifying high-water marks (HWMs). In September 2016, a cooperative study that focused on Odanah and surrounding areas, was done to further identify and survey HWMs and evaluate the magnitude of the flood, probability of occurrence, and extent of flood inundation. Near the flood study area are seven USGS continuous-record streamgages and six crest-stage gages (fig. 1).

Purpose and Scope

The purpose of this report is to provide hydrologic information pertaining to the recovery from the July 2016 flood in the vicinity of northern Wisconsin and specifically for the community of Odanah within the Bad River Reservation. The scope of the report includes (1) documentation of field measurements and analysis of peak-flow magnitudes and their statistical probability at selected locations in the vicinity of the Bad River (fig. 1) and (2) the flagging and surveying of HWMs and geographic information system (GIS) analysis of HWM locations and elevations to produce maps of flood inundation (extent of flooding) in the vicinity of Odanah, Wis. Flood-inundation maps were created for the Bad River from the USGS Bad River near Odanah streamgage (USGS identification number 04027000) to the community of Odanah. Flood-inundation maps also were created for the nearby tributaries of Beartrap Creek and Denomie Creek (fig. 3). All three rivers flow into a large coastal wetland complex associated with Lake Superior (fig. 3) near Odanah. This report is supported by a companion data release of digital flood-inundation maps (areal extent and depth of flooding) for the Bad River, Beartrap Creek, and Denomie Creek.

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[1]Natural Resources Department of the Bad River Band of the Lake Superior Chippewa Tribe.

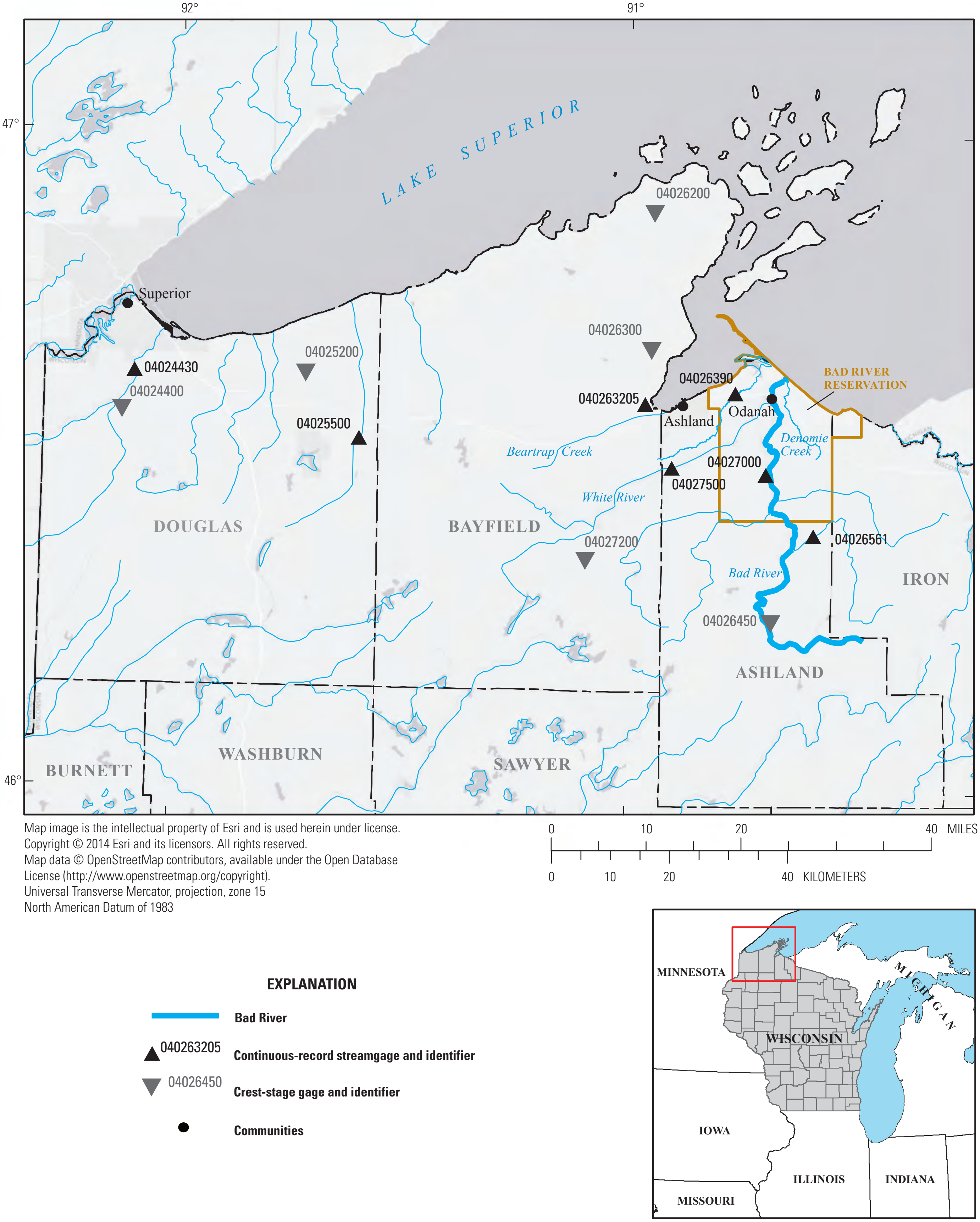

Figure 1. Study area in northern Wisconsin showing streamgages, river basins, and Bad River Reservation.

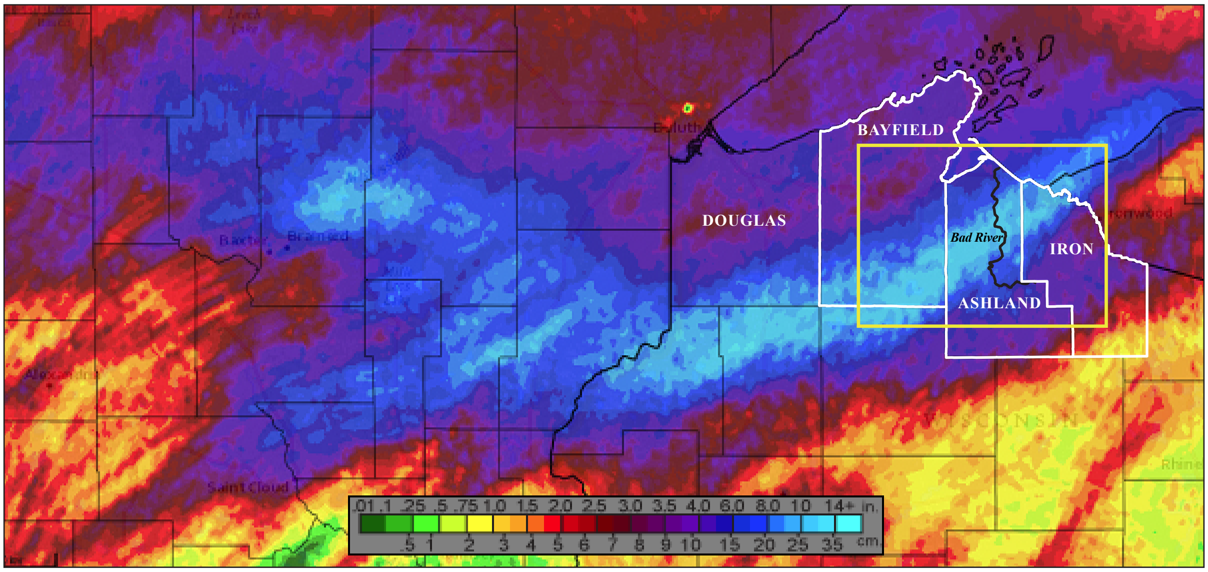

Figure 2. Cumulative radar rainfall estimates in northeastern Minnesota and northwestern Wisconsin for 5 a.m. July 11 to 5 a.m. July 12, 2016 (National Weather Service, 2016a).

Study Area

Areas affected by flooding described within this report are mainly within the Lake Superior Lowland Region of Wisconsin (Martin, 1916). In general, the area consists of relatively flat plains underlain by varying thickness of red clay and sloping to the north toward Lake Superior. The Bad River starts in the Northern Highland Region and cuts through steep escarpments associated with relict shorelines of ancient Lake Superior. An extensive wetland complex extends northward of Odanah toward Lake Superior. Land surface elevations range from about 603 feet (ft) at the shoreline with Lake Superior to greater than 1,500 ft in elevation relative to North American Vertical Datum of 1988 (NAVD 88) along the uplands to the south. The 30-year normal rainfall, from 1981–2010, for the Ashland Experimental Station, 10 miles west of Odanah, is 30.8 inches (U.S. Climate Data, 2016).

Methods

The "Methods" section provides a description of techniques used for estimation of the July 2016 flood magnitude and frequency, HWM identification and surveying, and flood-inundation mapping. The methods followed standard USGS techniques.

Probabilities of Peak Streamflows

The AEP for a particular flood is the probability or odds of that streamflow being equaled or exceeded in any given year. For example, an AEP of 0.01 is the same as a 1 percent chance of that flow magnitude being equaled or exceeded in any given year (Holmes and Dinicola, 2010). Stated another way, the odds are 1 in 100 that flow will equal or exceed that magnitude in any given year. The recurrence interval corresponding to a particular AEP is equal to 1 divided by the AEP. For example, the flood probability of 0.01 corresponds to a 100-year flood recurrence interval.

Discharges associated with AEPs of 0.20, 0.10, 0.04, 0.02, 0.01, 0.005, and 0.002 were estimated using the procedure recommended by the Interagency Advisory Committee on Water Data (1982), commonly called the Bulletin 17B procedure. Users of this procedure calculate flood probabilities by fitting systematic annual-peak-discharge data to a log-Pearson type III distribution. The USGS PeakFQ program (Flynn and others, 2006) was used with annual peak streamflow data through 2010 (Walker and others, 2017).

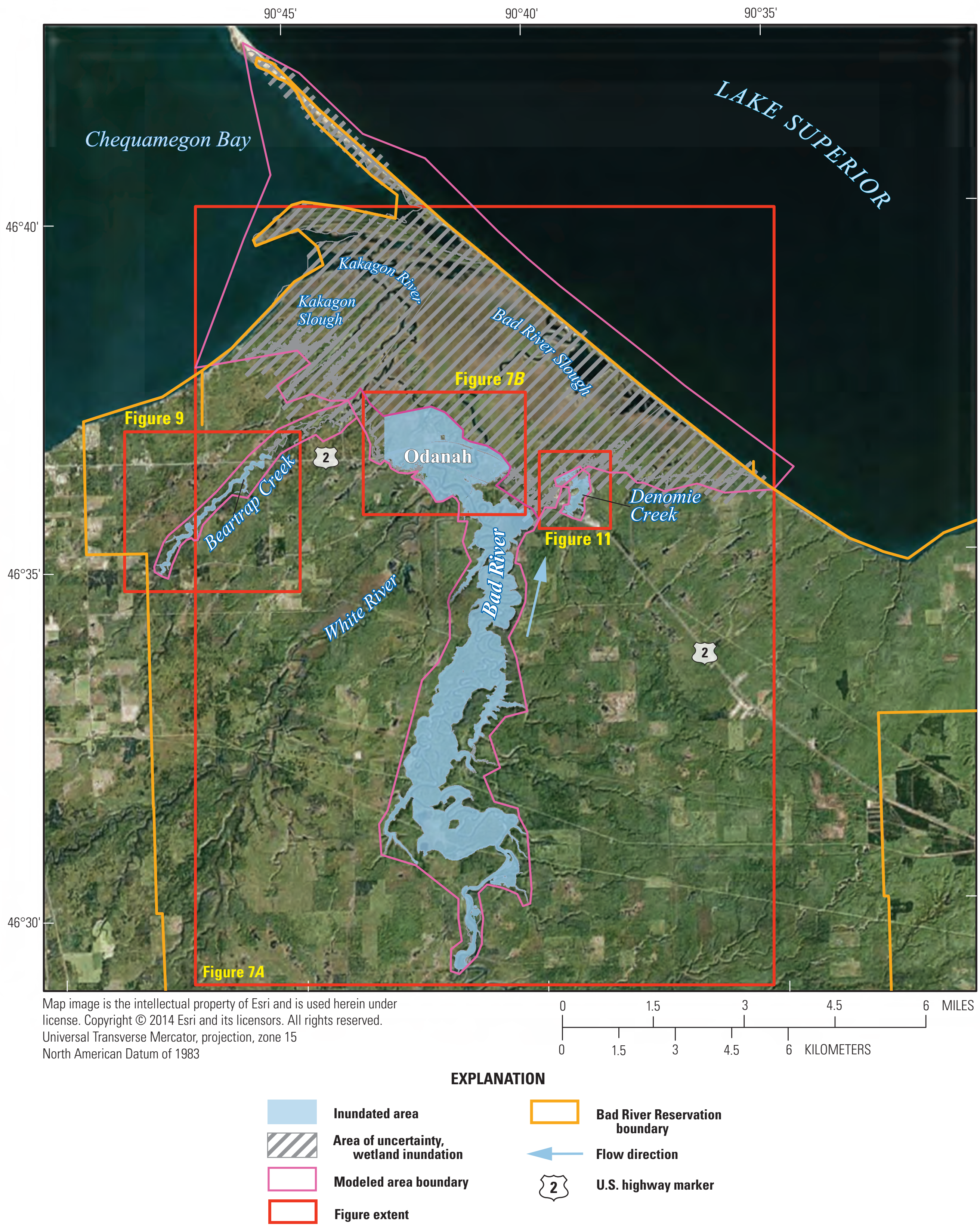

Figure 3. Location of flood inundation maps for the July 2016 flood event in northern Wisconsin and Bad River Reservation.

Collection of High-Water Mark Data

The collection of HWMs followed the USGS techniques described in Koenig and others (2016). The Bad River carries red clay in suspension and the muddy floodwaters left excellent mud lines on trees and leaves, some of which were still readily visible 2 months after the floods receded. A few HWMs were on buildings and other structures in the vicinity of Odanah (figs. 4*A*–4*F*).

The HWMs were identified and marked by the Bad River Tribe Natural Resources Department and the USGS in a 1–2 week period immediately following the flood. Additional HWMs were identified by the Bad River Tribe and the USGS through September 16, 2016, when all the marked HWMs were surveyed by the USGS with assistance from the Bad River Tribe. Identification marks included nails, paint lines, or flagging. Additional information included written descriptions, sketches, and photographs. General locations were recorded with various hand-held global positioning systems (GPS) to help with relocating the HWMs later for surveying. Although an attempt was made for consistent recording of information by both agencies, some HWM data were incomplete, such as quality ratings associated with the HWMs. Quality ratings ranged from excellent (±0.05 ft) to very poor (greater than 0.40 ft) (Koenig and others, 2016).

The HWMs were surveyed using four methods with varying accuracies. First, a real-time network global positioning system (RTN–GPS) was used for HWMs within cell network coverage, which was mainly west and south of Odanah. This method was the preferred method but only about one-quarter of the HWMs could be surveyed with the RTN–GPS. The RTN–GPS uses the Wisconsin Department of Transportation Continuously Operating Reference Stations (WISCORS) Network, a network of continuously operating GPSs that provide real-time correction to a rover GPS through a cellular data connection. The WISCORS track the U.S. navigation satellite timing and ranging system (NAVSTAR) GPS and the Russian Federation Global Navigation Satellite System (GLONASS). The surveyed elevations were expected to be within ±0.10 ft (Wisconsin Department of Transportation, 2017).

A real-time kinematic global positioning system (RTK–GPS) was used as a second method for HWMs in and to the north and east of Odanah that were outside the range of cell service. A base station was set up in an open area near the middle of the zone of HWMs near Odanah for an entire day of a survey. A rover, within radio distance, collected raw location and elevation coordinates via multiple NAVSTAR and GLONASS satellites. Following the survey, the Online Positioning User Service (National Oceanic and Atmospheric Administration, 2016) was used to compute adjusted and more accurate coordinate data. Similar to the RTN–GPS, the surveyed elevation were expected to be within ±0.10 ft.

For the RTK–GPS and RTN–GPS surveys, nearby National Geodetic Survey control points within radio or cell coverage were surveyed multiple times for maintaining quality assurance checks. For the final adjustments of the raw RTK–GPS data, three Wisconsin Department of Transportation geodetic survey control points were used. These points had a preferred vertical accuracy of second-order class I. For the RTK–GPS surveys, the difference between the Online Positioning User Service corrections and control point corrections was 0.09 ft. The datum used was the NAVD 88. These first two HWM survey methods were the most accurate.

The RTK–GPS and RTN–GPS surveys have a GPS rover unit on a 6-ft rod used to mark the coordinates of a HWM. Because most of the HWMs were on trees or next to buildings, the ability to set the GPS rover directly over a HWM to determine fixed-point coordinates was rare. A string, string level, and rod were used to accurately move a HWM elevation out from the blocked location to the rover (figs. 5*A*–5*C*).

A third method for surveying HWMs was associated with repeat channel cross-section surveys along the Bad River. These cross sections were about 500 ft downstream from the Bad River streamgage (USGS identification number 04027000), about 3.5 miles downstream from the streamgage and immediately downstream from the lower falls, and about 1,000 ft downstream from U.S. Highway 2. For these HWMs, the RTN–GPS was used to measure the elevation of local reference marks. A total station was used to measure the elevation of the HWM indicators and the local reference marks allowed for the HWMs to be converted to NAVD 88 (fig. 5*A*). The total station cross-section surveys had an accuracy of ±0.05 ft, giving these HWMs a similar survey accuracy as the first two methods.

A fourth set of HWMs, mainly along the remote stretch of the Bad River between the Bad River near Odanah streamgage (USGS identification number 04027000) and the community of Odanah, were horizontally located with a nonsurvey grade hand-held GPS (Garmin Oregon 750 series). Horizontal GPS accuracy ranged from about 5 to 10 ft. Elevations for the remote HWMs were estimated from tape ups to the HWM indicator from ground surface. The remote HWMs were overlaid onto a lidar- (light detection and ranging) based 1-meter bare earth raster (digital elevation model, [DEM]) flown in 2014–15 for Ashland County (fig. 1; A. Kirschbaum, National Park Service, written commun., August 2016). The tape-up distance to the HWM was added to the DEM-based ground-surface elevation for the final HWM elevation. The hand-held GPS HWMs with lidar elevations have an expected vertical accuracy of about ±5 ft because of the range of variability caused by a horizontal offset in varying riverine-related topography.

After surveying, 108 HWMs were plotted in ArcGIS and locational information checked against field notes and photographs. Locational data and descriptions for the HWMs were entered into the USGS short-term network, as the Wisconsin July 2016 flood. The short-term network is a USGS database and program for entering HWMs in real time. The flood event viewer is an online interface created to facilitate the dissemination of field data on the USGS flood information website (U.S. Geological Survey, 2016). For the flood event viewer,

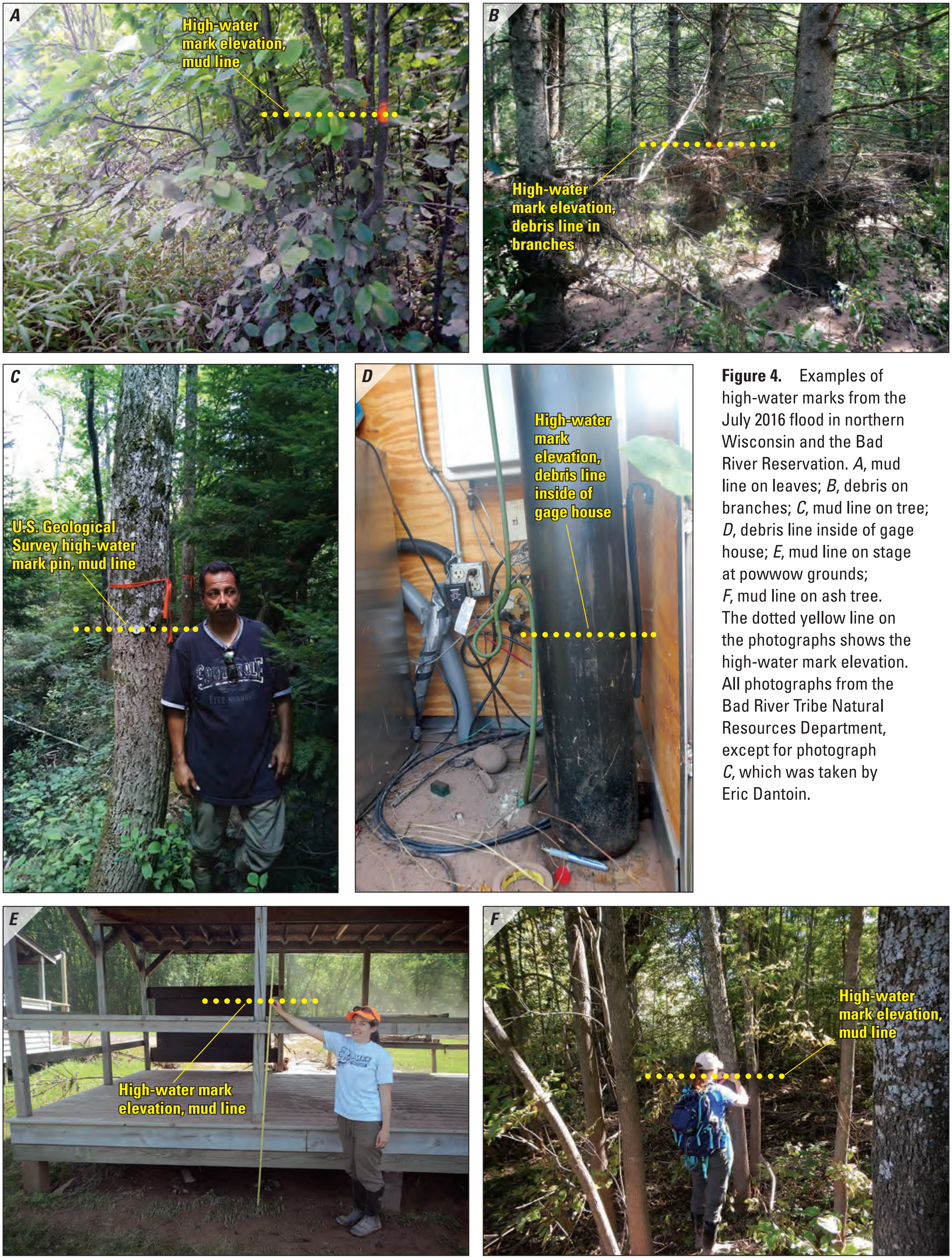

Figure 4. Examples of high-water marks from the July 2016 flood in northern Wisconsin and the Bad River Reservation. *A*, mud line on leaves; *B*, debris on branches; *C*, mud line on tree; *D*, debris line inside of gage house; *E*, mud line on stage at powwow grounds; *F*, mud line on ash tree. The dotted yellow line on the photographs shows the high-water mark elevation. All photographs from the Bad River Tribe Natural Resources Department, except for photograph *C*, which was taken by Eric Dantoin.

Figure 5. Examples of surveying high-water marks: *A*, total station; *B*, leveled string to RTN–GPS; *C*, leveled string to RTK–GPS. The dotted yellow line on the photographs shows the high-water mark elevation. Photographs from the Bad River Tribe Natural Resources Department.

the 108 HWMs were grouped into 68 sites based on the proximity of a HWM to another HWM (table 1–1). For example, if multiple HWMs were in a patch of trees upstream from a bridge and on the same side of the river, the HMWs would be grouped together into one site.

The 108 HWMs, along with the flood stage at the Bad River near Odanah streamgage of 695.68 ft (NAVD 88) and the average daily water level of Lake Superior at Ontonagon, Michigan (not shown), on July 12, 2016, of 602.83 ft (NAVD 88), were used to create flood-inundation maps.

Flood-Inundation Mapping

Three flood-inundation maps were created by overlapping the HWM elevations in the vicinity of the Bad River, Beartrap Creek, and Denomie Creek with the Ashland County DEM data in a GIS. The GIS methods used to create the flood-inundation maps follow methods described in Musser and others (2016) and Morlock and others (2008). These maps show the maximum extent of floodwaters associated with the July 2016 flood. The maps were superimposed on the latest online USGS aerial orthoimagery and Esri world imagery (location specific). The maps were subsequently checked by Bad River Tribe and USGS staff against photographs taken during the flooding. Especially pertinent were the areas of U.S. Highway 2 that were overtopped, which caused most of the residential areas and the Bad River Lodge and Casino to be cut off from vehicle transportation for several days until floodwaters receded and washed-out bridges were repaired.

Uncertainties in the resulting flood-inundation maps depend mainly on the number and spatial distribution of HWMs, as well as the identification and surveying accuracy of the HWMs and the DEM. Additionally, hydraulic models were not used to create the flood-inundation extents or depths. Exact timing of flood flows from tributaries is not known.

The flood spatial extent was interpolated between HWM points. The ArcGIS Topo to Raster tool was used to produce a plane representing the flood-peak water-surface elevation, which was fit through the HWMs and cross-section lines across the river reaches. Elevations between HWMs are proportional interpolations of the HWM data. A triangular irregular network surface was fit through the data points, forming the estimated flood surface elevation raster. A flood-depth map was made by subtracting the DEM of the land surface from the flood-peak water-surface elevation raster. Flood depths over the river are representative of the river water surface at the time that the lidar for the DEM was flown. The flood-peak inundated area triangular irregular network models were exported in a GIS file format (shapefiles) that delineates flood-peak extent.

Flood-Peak Profiles

Flood-peak profiles for the Bad River, Beartrap Creek, and Denomie Creek were produced by plotting HWM elevations by mile of stream as measured along the centerline of the flooded area (Benson and Dalrymple, 1967; Lumia and others, 1986). A subset of HWMs was used by selecting a single HWM elevation for those grouped into flood event viewer sites closest to the rivers. The HWM with the highest quality rating and best survey accuracy was included in the subset. The Bad River profile was plotted from the Bad River near Odanah streamgage (USGS identification number 04027000) to its mouth at Lake Superior. Profiles for Beartrap Creek and Denomie Creek used the same river mile for the Bad River coincident their intersection with U.S. Highway 2. The water surface between HWMs was estimated by linear interpolation. A linear interpolation between HWMs is an approximation of the actual water surface.

Flood of July 2016 in Northern Wisconsin and the Bad River Reservation

The estimated AEPs of peak streamflows for the flood of July 2016 in the vicinity of Odanah, Wis., are presented. Flood-peak inundation maps and flood-peak water-surface profiles for three streams in the flooded area also are presented.

Estimated Magnitudes and Annual Exceedance Probabilities of Peak Streamflows

Flood-peak gage heights, peak streamflow, and corresponding AEPs were determined for the July 2016 flood for seven continuous-record streamgages and six crest-stage gages (table 1). The data listed in table 1 currently (October 2016) are considered provisional pending final approval. The locations of streamgages used for the analysis are shown in figure 1. The gage height for the Bad River streamgage (USGS identification number 04027000) peak streamflow (AEP less than 0.002) was more than 5 ft higher than the previous record in 1960. The gage height for the Nemadji River (USGS identification number 04024430) (not shown) peak streamflow also had an AEP of less than 0.002, but overall did not exceed the previous record from 2011. The gage height of the White River (USGS identification number 04027500) peak streamflow had a slightly lower AEP of 0.005–0.01. Estimation of peak streamflow at Twentymile Creek (USGS identification number 04027200) (not shown), a tributary to the White River, was not possible because of a very large washout of the road crossing at the crest-stage gage. Streams on the Bayfield Peninsula were out of the storm-affected area.

Table 1. Flood-peak gage heights, peak streamflows, and annual exceedance probabilities of peak streamflows during the flood of July 2016 at selected U.S. Geological Survey streamgages in northern Wisconsin and the Bad River Reservation.

[mi^2, square mile; ft^3/s, cubic foot per second; %, percent; Wis., Wisconsin; e, estimated; <, less than; >, greater than; –, flood discharge data not available]

U.S. Geological Survey identification number	Stream and place of determination	Drainage area (mi^2)	Water year [1] with peak streamflow records	Peak streamflow for period of record prior to water year[1] 2016			Peak streamflow for July 11–12, 2016 flood			Annual exceedance probability[3] for July 2016 peak streamflow	Estimated streamflow of 0.01 (1%) annual exceedance probability[3]
				Date	Gage height (feet above gage datum[2])	Discharge (ft^3/s)	Date	Gage height (feet above gage datum[2])	Discharge (ft^3/s)		
04024430	Nemadji River near South Superior, Wis.	420	1973–2015	8/3/2011	27.37	33,000	7/12/2016	26.07 e	15,600 e	<0.002	12,800
04025500	Bois Brule River at Brule, Wis.	118	1942–81, 1984–2015	4/23/2001	7.24	1,860	7/12/2016	3.58	583	>.20	1,820
040263205	Whittlesey Creek near Ashland, Wis.	7.4	1999–2015	6/21/2013	7.29	1,010	7/11/2016	6.23	695	0.10–0.20	2,070
04026390	Beartrap Creek near U.S. Highway 2 near Ashland, Wis.	22.6	2008–2015	5/20/2013	14.68	1,500	7/12/2016	16.80	[4]2,930	Undetermined[5]	Undetermined[5]
04026561	Tyler Forks River at Stricker Road near Mellen, Wis.	70.5	2011–2015	5/1/2013	11.38	1,910	7/12/2016	14.20	[4]3,150	Undetermined[5]	Undetermined[5]
04027000	Bad River near Odanah, Wis.	597	1948–2015	4/24/1960	21.70	27,700	7/12/2016	27.28	[4]40,000	<0.002	24,100
04027500	White River near Ashland, Wis.	301	1948–2015	7/24/2005	7.18	6,720	7/12/2016	8.54	[4,6]7,990	0.005–0.01	8,240
[7]04024400	Stony Brook near Superior, Wis.	1.86	1959–2015	9/2/1985	35.23	595	7/12/2016	12.37	–	–	652
[7]04025200	Pearson Creek near Maple, Wis.	4.07	1957–2015	9/2/1985	31.83	1,440	7/12/2016	11.23	542	>.20	1,860
[7]04026200	Sand River Tributary near Red Cliff, Wis.	1.09	1959–2015	5/24/1964	16.86	624	7/12/2016	11.08	101	>.20	622
[7]04026300	Sioux River near Washburn, Wis.	13.7	1959–2015	4/24/1960	17.48	1,620	7/12/2016	12.79	624	>.20	2,650
[7]04026450	Bad River near Mellen, Wis.	82	1971–2015	5/12/2003	9.59	2,880	7/12/2016	7.80	1,780	>.20	3,410
[7]04027200	Twentymile Creek at Grandview, Wis.	13.8	1960–2015	7/2/1992	28.47	1,920	7/12/2016	39.24	–	–	973

[1]A water year is the 12-month period from October 1 through September 30 and is designated by the calendar year in which it ends. For some sites, records include annual peak flow data only.

[2]Elevation from vertical datum has not been established.

[3]The annual exceedance probability is the probabilty that a given event magnitude will be equaled or exceeded in any given year and is the reciprocal of the recurrence interval. The recurrenc interval is the average interval of time within which the given flood will be equaled or exceeded once (American Society of Civl Engineers, 1953, p. 1221).The annual exceedance probability for a recurrence interval of 10 years is 0.10 (10%); for 25 years, 0.04 (4%), for 50 years, 0.02 (2%), for 100 years, 0.01 (1%), and for 500 years, 0.002 (0.2%). Probabilities were last estimated through water year 2010 (Walker and others, 2017).

[4]New streamflow peak of record.

[5]Annual exceedance probabilities were not calculated for stations with less than 10 years of record.

[6]Streamflow affected by nearby hydroelectric dam.

[7]U.S. Geological Survey crest-stage gage.

Hydrographs for July 2016 for the at the Bad River near Odanah (USGS identification number 04027000), White River near Ashland (USGS identification number 04027500), Tyler Forks River at Stricker Road near Mellen (USGS identification number 04026561), and Beartrap Creek near U.S. Highway 2 near Ashland (USGS identification number 04026390) streamgages illustrate the peak streamflows associated with the July 2016 flooding and the flashiness of the rivers because of the steep terrain and clayey soils (fig. 6). All four streamgages continuously operated during the flood, although floodwaters partially inundated the monitoring equipment enclosures at Beartrap Creek (fig. 4*D*).

At the Bad River near Odanah streamgage (USGS identification number 04027000), streamflow started to rise quickly from 300 cubic feet per second (ft^3/s) at about 8 p.m. on July 11 to a record peak of 39,700 ft^3/s on July 12 at about 11 a.m. The peak streamflow for the Bad River was the highest recorded at the streamgage since inception of the streamgage in 1948.

The peak at the White River near Ashland streamgage (USGS identification number 04027500) is similar, followed by a more sustained high flow period through July 20th, likely reflecting the slower draining of the large marsh complex, called Bibon Marsh, in the headwaters of the White River (not shown). The White River enters the Bad River just south of U.S. Highway 2 and has a hydrodam operated by Xcel just upstream from the USGS streamgage. The occasional spikes shown on the hydrograph for the White River are likely related to dam operations.

The peak streamflow at the Beartrap Creek near U.S. Highway 2 near Ashland streamgage (USGS identification number 04026390) was slightly larger than at the Tyler Forks River at Stricker Road near Mellen streamgage (USGS identification number (04026561), although the drainage area of Beartrap Creek is about one-third of Tyler Forks River (table 1). The Tyler Forks River at Stricker Road near Mellen streamgage was the first of the four streamgages to record a peak around midnight of July 11. The flow variations at Beartrap Creek during flows below about 10 ft^3/s are an artifact of stage changes at the streamgage associated with backwater from Lake Superior seiches.

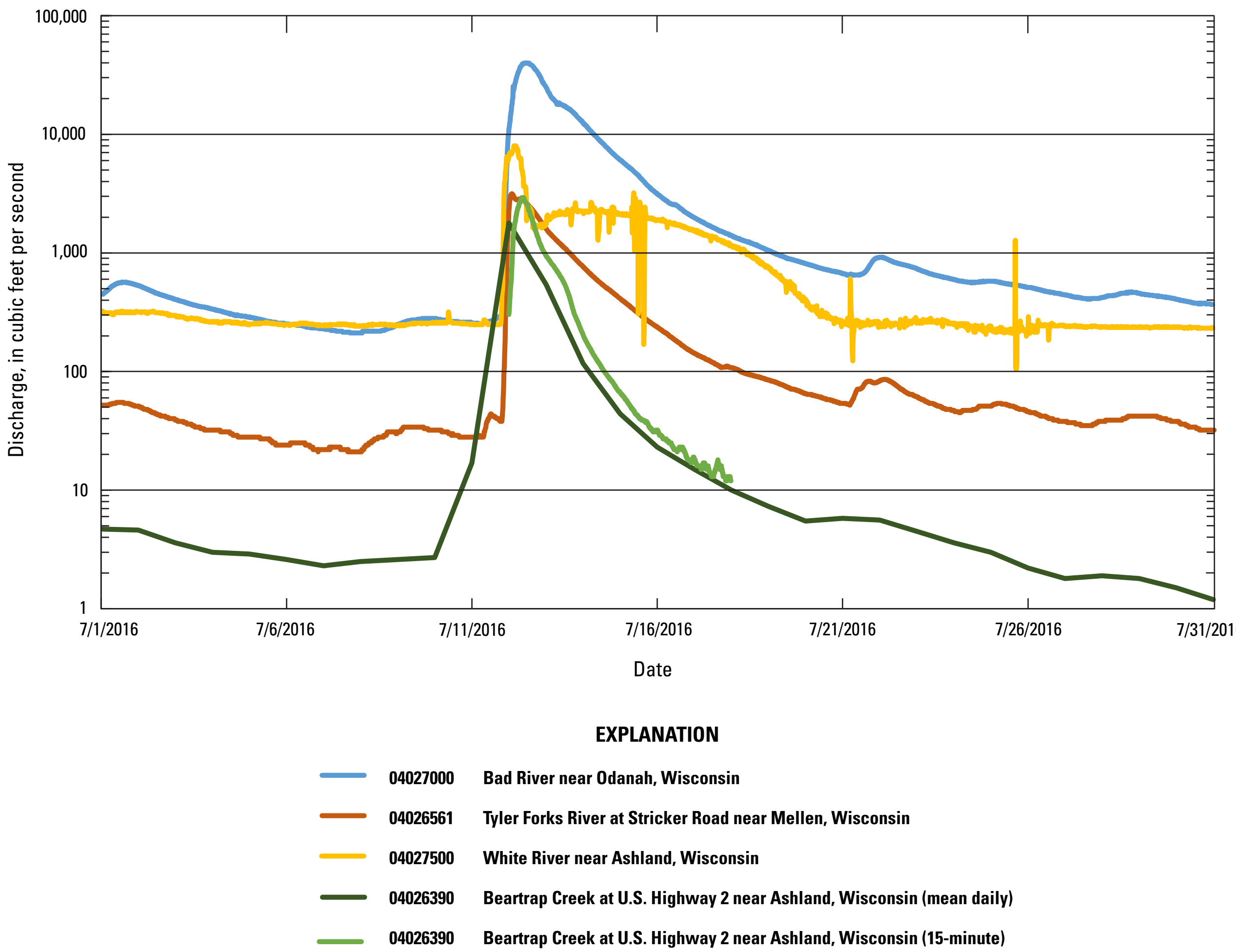

Figure 6. Flood hydrographs for selected U.S. Geological Survey streamgages in northern Wisconsin for July 2016. Locations of streamgages are shown on figure 1.

Flood-Peak Inundation Maps

Flood-peak inundation maps were created for the Bad River, Beartrap Creek, and Denomie Creek in the vicinity of Odanah, Wis. All 108 HWMs collected were used to develop the inundation maps. The HWMs used in the inundation mapping and associated information are included in the USGS HWM flood event viewer (U.S. Geological Survey, 2016) and are listed in appendix table 1–1. Digital datasets of the flood-inundation area, study boundary, water depth rasters, and final map products can be downloaded from the USGS Science Data Catalog (Watson and others, 2017). The inundation maps show the maximum extent and depth of floodwaters. Inundated areas shown should not be used for navigation, regulatory, permitting, or other legal purposes. The U.S. Geological Survey 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.

Bad River

The areal extent of flood inundation for the Bad River is shown in figure 7*A* with an enlarged portion of the map for the Odanah area shown in figure 7*B*. The upstream end of the Bad River flood-inundation map starts about 150 ft downstream from Elm Hoist Road (fig. 7*A*), at the Bad River near Odanah streamgage (USGS identification number 04027000). The downstream end of the Bad River flood-inundation map is just north of U.S. Highway 2. The water-surface elevation ranged from 609.14 ft (185.66 meters) at the downstream end to 695.62 ft (212.02 meters) at the upstream end. The flood surface was extended (with more uncertainty) to the mouth of the Bad River at Lake Superior (assumed stage of 602.83 ft NAVD 88). Lake Superior can vary by 1 ft or more because of frequent seiches. The estimated areal coverage connecting the Bad River floodwaters to Lake Superior is shown with a hatched symbol in figures 7*A*–7*B*. The high concentration of HWMs surrounding U.S. Highway 2 coincides with the western side of the community of Odanah and the confluence of the White River entering the Bad River from the southwest (fig. 7*B*).

The floodwaters combined from the Bad and White Rivers flowed over U.S. Highway 2 to the east and west of the Bad River bridge, mixing with water in the Kakagon River and Kakagon and Bad River Sloughs (fig. 3) and eventually flowing into Chequamegon Bay and Lake Superior (fig. 7*A*). Photographs illustrating the flooding in this vicinity are shown in figures 8*A*–8*F*. The Bad River did not overtop the bridge and its approach at U.S. Highway 2.

Beartrap Creek

Flood inundation related to Beartrap Creek extended from HWMs upstream and downstream from County Road A for about 2 miles to the U.S. Highway 2 crossing (fig. 9). The flows of Beartrap Creek did not overtop the road or bridge (fig. 10) but did partially inundate the USGS streamgage enclosure (fig. 4*D*). Floodwaters from Beartrap Creek enter Kakagon River and adjacent sloughs to the north of U.S. Highway 2 and eventually mixed with floodwaters of the Bad River entering Chequamegon Bay (fig. 3). Similar to the Bad River, the flood surface was extended (with more uncertainty) to the mouth of the Kakagon River at Chequamegon Bay (assumed the Bay was at the same stage of 602.83 ft NAVD 88 used for Lake Superior) (not shown on figure 9).

Denomie Creek

Inundation mapping along the Denomie Creek was done near the eastern side of Odanah and the Bad River Lodge and Casino (fig. 11). The mapping started about 300 ft southwest of U.S. Highway 2 and about 1.3 miles downstream into the Bad River Slough adjacent to Lake Superior. The inundation depth map was developed from 12 HWMs. The water-surface elevation ranged from 618.93 ft (188.65 meters) at the downstream end to 634.84 ft (193.50 meters) at the upstream end. The U.S. Highway 2 bridge over Denomie Creek was partially washed out by the flooding (fig. 12*A*), and roads and buildings were inundated in the residential areas in the community of Odanah (fig. 12*B*). The inundation map shows water totally over U.S. State Highway 2 from Denomie Creek for about a 50–100 ft section (fig. 11). Mud and washouts along the north side of the road indicate that possibly 400 ft of U.S. Highway 2 was inundated (fig. 12*A*).

Water-Surface Profiles

The longitudinal water-surface profiles determined from the HWMs for the Bad River, Beartrap Creek, and Denomie Creek along the centerline of each flooded area were overlaid onto one graph, using the crossing location of U.S. Highway 2 as a common feature and same longitudinal distance for all three profiles (fig. 13). The plot for the Bad River is the most extensive, starting with the Bad River near Odanah streamgage (USGS identification number 04027000) about 14 miles upstream from its mouth at Lake Superior, as measured along the centerline of the flooded area (not the longer meandering streamline). Additional information was added to the plots, such as the locations of road crossings.

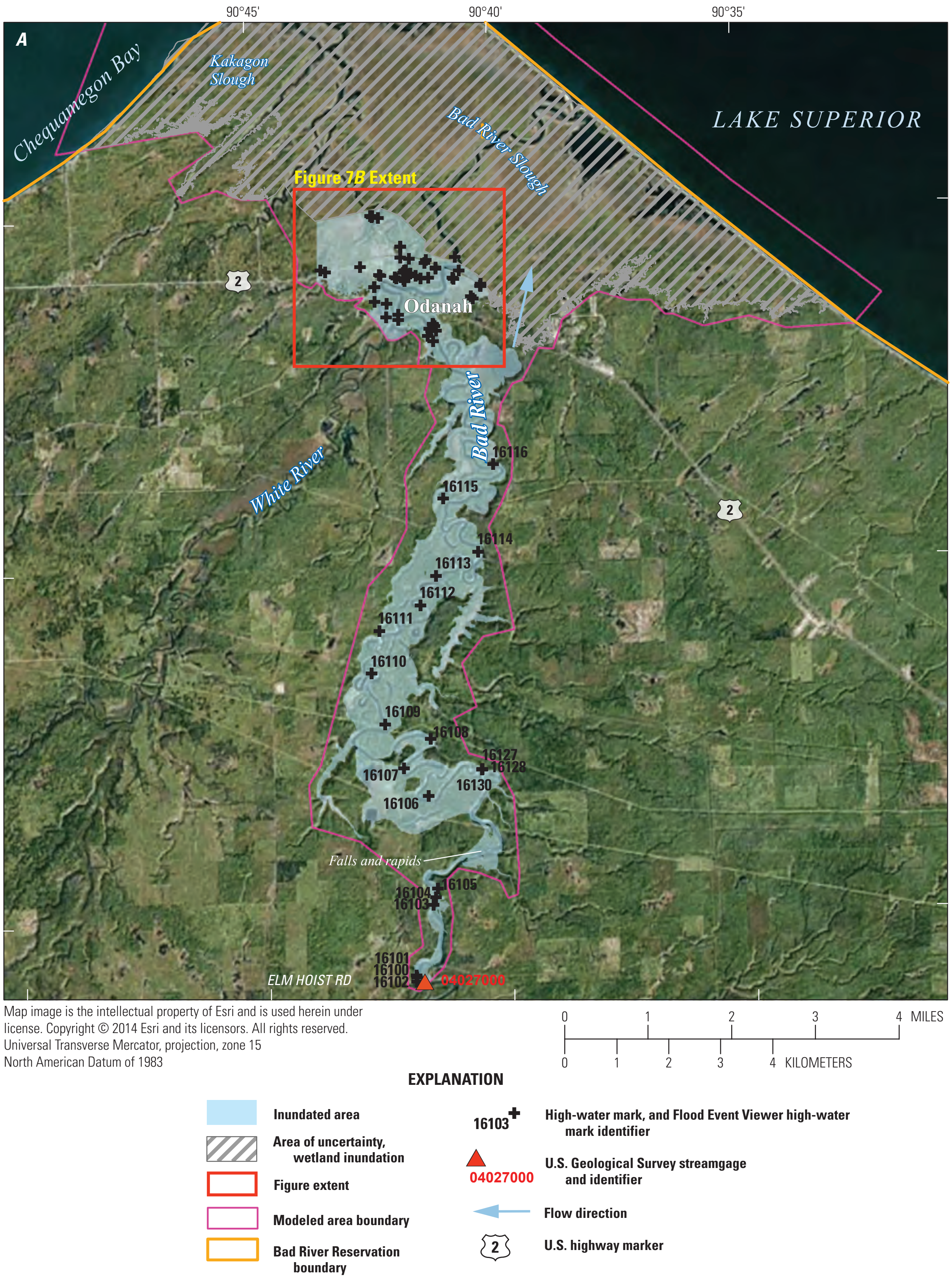

Figure 7. Approximate extent of flood-peak inundation, flood of July 2016. *A*, the Bad River from the Bad River near Odanah, Wisconsin, streamgage (USGS identification number 04027000) to its mouth at Lake Superior; and *B*, the Bad River near U.S. Highway 2 and Odanah, Wisconsin.

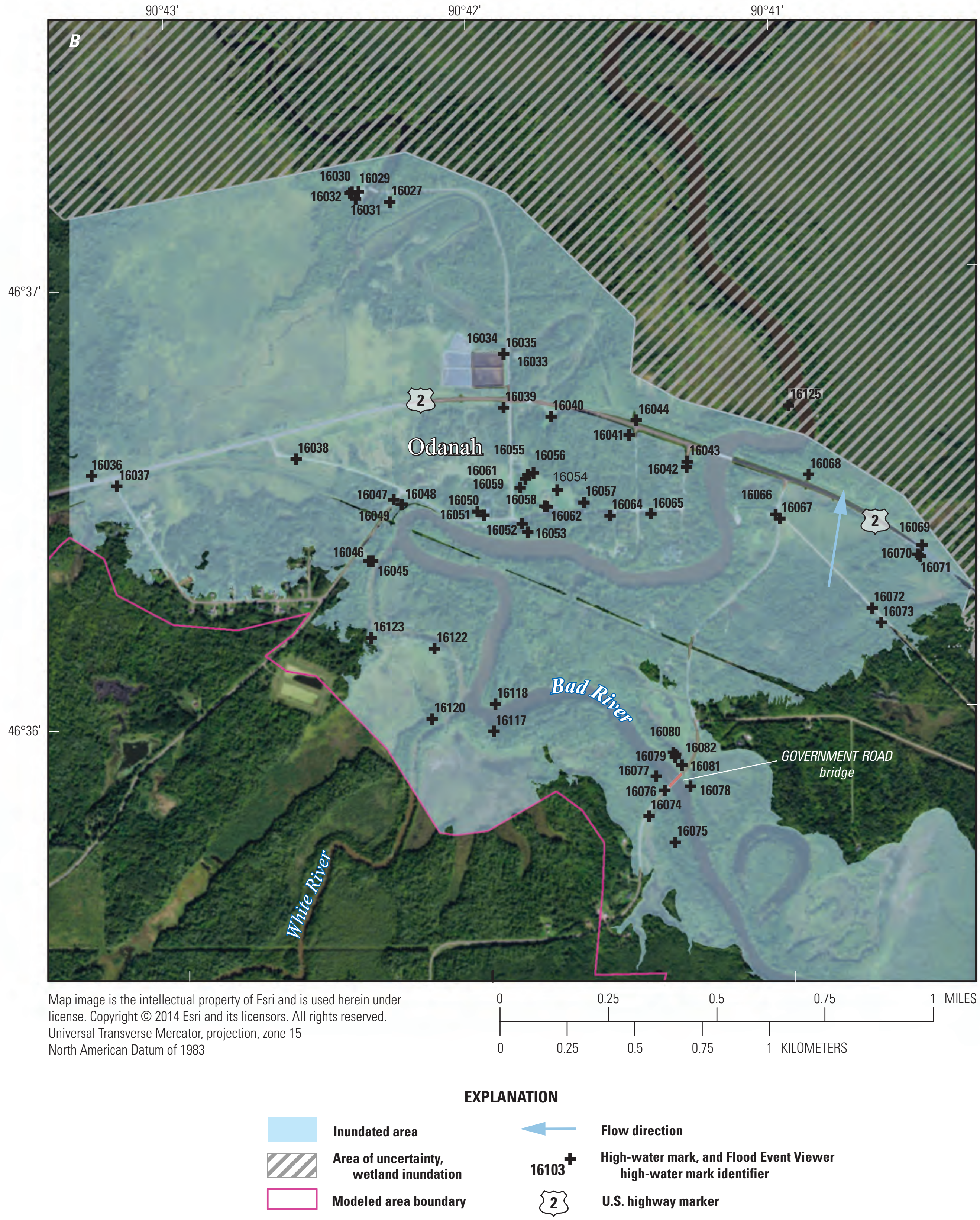

Figure 7. Approximate extent of flood-peak inundation, flood of July 2016. *A*, the Bad River from the Bad River near Odanah, Wisconsin, streamgage (USGS identification number 04027000) to its mouth at Lake Superior; *B*, the Bad River near U.S. Highway 2 and Odanah, Wisconsin.—Continued

Figure 8. Photographs of flooding in the vicinity of Odanah, Wisconsin, caused by the combined floodwaters of the White and Bad Rivers. *A*, looking east at a flooded portion of U.S. Highway 2 east of the Bad River bridge crossing; *B*, aerial view of flooded portion of U.S. Highway 2 west of Kakagon Road; *C*, flooded portion of Kakagon Road looking east from the fish hatchery; *D*, aerial view of flooding of the Kakagon River at Kakagon Road crossing with fish hatchery on the west (left) side; *E*, looking north at a flooded intersection at Old Odanah Road and Old U.S. Highway 2; *F*, aerial view of flooding along Old Odanah Road, St. Mary Catholic Church, and powwow grounds. Photographs from the Bad River Tribe Natural Resources Department and Emergency Management.

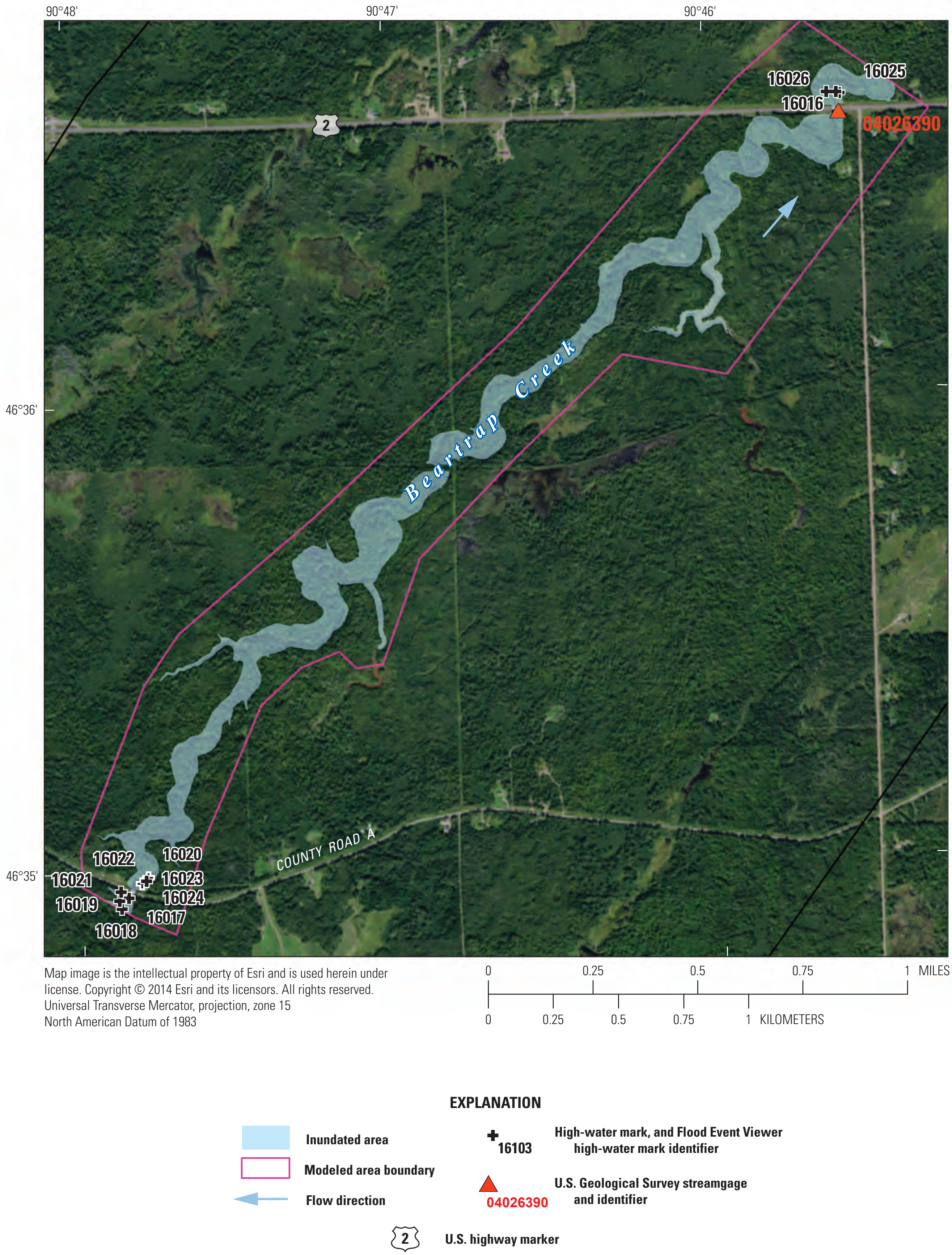

Figure 9. Approximate extent of flood-peak inundation, flood of July 2016, for Beartrap Creek near Odanah, Wisconsin.

Figure 10. Photograph of flooded Beartrap Creek and the U.S. Geological Survey streamgage enclosure on July 12, 2016. Photograph by Naomi Tillison, Bad River Tribe Natural Resources Department.

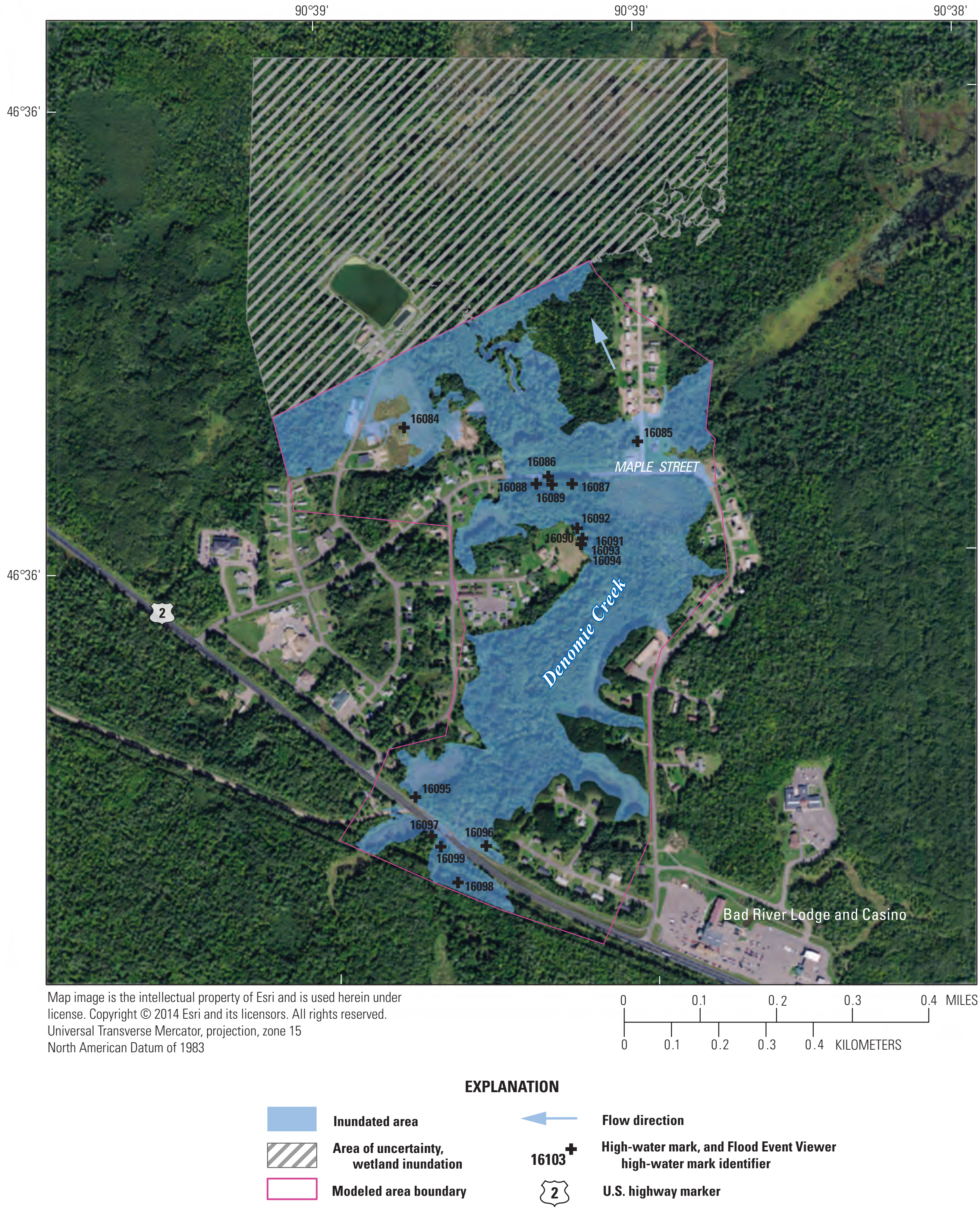

Figure 11. Approximate extent of flood-peak inundation, flood of July 2016, for Denomie Creek near the Bad River Lodge and Casino, Odanah, Wisconsin.

Figure 12. Photograph for the July 2016 flood for Odanah, Wisconsin, associated with floodwaters of Denomie Creek near the community of Odanah. *A*, flood damage at the U.S. Highway 2 bridge; *B*, flooded areas looking north along Maple Street. Photographs from the Bad River Band of Lake Superior Chippewa Tribe (https://www.badriver-nsn.gov/2016-flood-update).

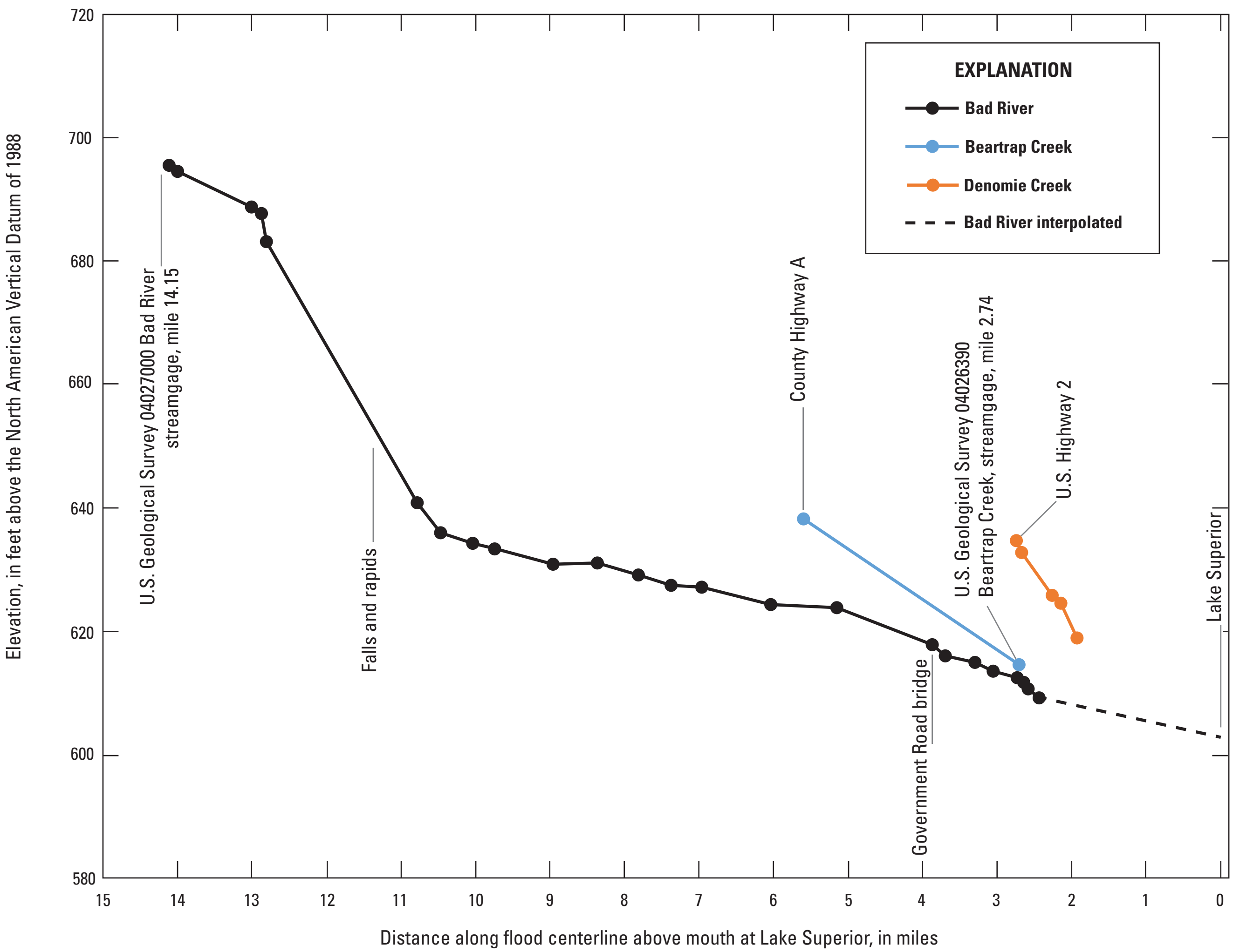

Figure 13. Graph showing flood-peak water-surface profiles for the Bad River, Beartrap Creek, and Denomie Creek, for the flood of July 2016.

Summary

On July 11–12, 2016, the Bad River and nearby streams flooded the community of Odanah, Wisconsin, in the Bad River Reservation. After the flooding, Bad River Tribe Natural Resources Department and U.S. Geological Survey personnel identified and documented 108 high-water marks. The high-water marks were used to create three flood-inundation maps that show the extent of and depths of inundation near the lower Bad River, Beartrap Creek, and Denomie Creek. Maps created to show the areal extent and depth of inundation are available for download from the USGS Science Data Catalog. Peak gage heights, peak streamflows, and estimated annual exceedance probabilities were provided for seven streamgages and six crest-stage gages operated by the U.S. Geological Survey in the vicinity of the Bad River Reservation.

References Cited

American Society of Civil Engineers, 1953, Review of flood frequency methods—Final report of the subcommittee on the joint division committee on floods: Transactions of the American Society of Civil Engineers, v. 118, no. 1, p. 1220–1230.

Benson, M.A., and Dalrymple, Tate, 1967, General field and office procedures for indirect measurements: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A1, 30 p.

Czuba, C.R., Fallon, J.D., Kessler, E.W., 2012, Floods of June 2012 in Northeastern Minnesota: U.S. Geological Survey Scientific Investigations Report 2012–5283, 42 p., 3 app.

Flynn, K.M., Kirby, W.H., and Hummel, P.R., 2006, User's manual for program PeakFQ, annual flood-frequency analysis using Bulletin 17B guidelines: U.S. Geological Survey Techniques and Methods, book 4, chap. B4, 42 p.

Holmes, R.R., Jr., and Dinicola, Karen, 2010, 100-Year flood—It's all about chance: U.S. Geological Survey General Information Product 106, 1 sheet. [Also available at https://pubs.usgs.gov/gip/106/.]

Interagency Advisory Committee on Water Data, 1982, Guidelines for determining flood flow frequency: Bulletin 17B of the Hydrology Subcommittee, Office of Water Data Coordination, U.S. Geological Survey, Reston, Va., 183 p.

Koenig, T.A, Bruce, J.L., O'Connor, J.E., McGee, B.D., Holmes, R.R., Jr., Hollins, Ryan, Forbes, B.T., Kohn, M.S., Schellekens, M.F., Martin, Z.W., and Peppler, M.C., 2016, Identifying and preserving high-water mark data: U.S. Geological Survey Techniques and Methods, book 3, chap. A24, 47 p. [Also available at https://dx.doi.org/10.3133/tm3A24.]

Langbein, W.B., and Iseri, K.T., 1960, General introduction and hydrologic definitions—Manual of hydrology, part 1, general surface-water techniques: U.S. Geological Survey Water-Supply Paper 1541–A, 29 p., accessed January 3, 2017, at https://pubs.er.usgs.gov/publication/wsp1541A.

Lumia, Richard, Burke, P.M., and Johnston, W.H., 1987, Flooding of December 29, 1984, through January 2, 1985, in northern New York State, with flood profiles of the Black and Salmon Rivers: U.S. Geological Survey Water-Resources Investigations Report 86–4191, 53 p.

Martin, L., 1916, The physical geography of Wisconsin: Wisconsin Natural History Bulletin No. 36, 636 p.

Morlock, S.E., Menke, C.D., Arvin, D.V., and Kim, M.H., 2008, Flood of June 7–9, 2008, in central and southern Indiana: U.S. Geological Survey Open-File Report 2008–1322, 15 p., 3 app. [Also available at https://pubs.usgs.gov/of/2008/1322/.]

Musser, J.W., Watson, K.M., Painter, J.A., and Gotvald, A.J., 2016, Flood-inundation maps of selected areas affected by the flood of October 2015 in central and coastal South Carolina: U.S. Geological Survey Open-File Report 2016–1019, 81 p. [Also available at https://dx.doi.org/10.3133/ofr20161019.]

National Oceanic and Atmospheric Administration, 2016, OPUS—Online positioning user service: National Geodetic Survey website, accessed January 11, 2017, at https://www.ngs.noaa.gov/OPUS/.

National Weather Service, 2016a, July 11, 2016 Flash flooding and high winds—Latest information: accessed September 29, 2016, at https://www.weather.gov/dlh/flash-flooding-2016-07-11.

National Weather Service, 2016b, Northern Wisconsin, 11–12 July 2016–Annual exceedance probabilities (AEPs) for the worst case 6-hour rainfall: accessed January 11, 2017, at http://www.nws.noaa.gov/ohd/hdsc/aep_storm_analysis/AEP_Northern_Wisconsin_July2016.pdf.

U.S. Climate Data, 2016, Climate data for Ashland, Wisconsin: accessed September 29, 2016, at http://www.usclimatedata.com/climate/ashland/wisconsin/united-states/uswi0031.

U.S. Geological Survey, 2011, Water resources of the United States—2011 Annual Data Report—Definition of terms: U.S. Geological Survey Water-Data Report WDR–US–2011, accessed November 19, 2012, at http://wdr.water.usgs.gov/wy2011/termDefs.html.

U.S. Geological Survey, 2016, USGS flood event viewer—Providing hurricane and flood response data: U.S. Geological Survey Flood Information website, accessed November 1, 2016, at https://water.usgs.gov/floods/FEV/.

Walker, J.F., Peppler, M.C., Danz, M.E., and Hubbard, L.E., 2017, Flood-frequency characteristics of Wisconsin streams: U.S. Geological Survey Scientific Investigations Report 2016–5140, 33 p., 1 plate, 2 appendixes, https://doi.org/10.3133/sir20165140.

Watson, K.M., Fitzpatrick, F.A., and Blount, J.D., 2017, Flood inundation, flood depth, and high-water marks associated with the flood of July 2016 in northern Wisconsin and the Bad River Reservation: U.S. Geological Survey data release, https://doi.org/10.5066/F78C9THZ.

Wisconsin Department of Transportation, 2017, WISCORS (Wisconsin continuously operating reference station) network: accessed January 11, 2017, at http://wisconsindot.gov/Pages/doing-bus/eng-consultants/cnslt-rsrces/tools/wiscors/default.aspx.

Wisconsin Public Radio, 2016, Northern Wisconsin receives federal disaster declaration: accessed September 29, 2016, at http://www.wpr.org/northern-wisconsin-receives-federal-disaster-declaration.

Glossary

The following definitions, except where otherwise noted, are from Langbein and Iseri (1960) and repeated from Czuba and others (2012).

annual exceedance probability The probability that a given event magnitude will be exceeded or equaled in any given year. The annual exceedance probability is directly related to the recurrence interval. For example, the chance that the 100-year peak flow will be exceeded or equaled in any given year is 1 percent. A flood probability of 0.01 has a recurrence interval of 100 years. The recurrence interval corresponding to a particular flood probability is equal to 1 divided by the flood probability (Holmes and Dinicola, 2010).

continuous-record streamgage A site where data are collected with sufficient frequency to define daily mean values and variations within a day.

crest-stage gage A partial-record streamgage that is nonmechanical, nontelemetered, and intended to record only the peak (crest) stream level since the last site visit.

flood peak The highest value of the stage or discharge attained by a flood; thus, peak stage or peak discharge. "Flood crest" has nearly the same meaning, but because it connotes the top of the flood wave, flood crest is properly used only in referring to stage—thus, "crest stage," but not "crest discharge."

flood profile A graph of elevation of the water surface of a river in flood, plotted as ordinate, against distance, measured in the downstream direction, plotted as abscissa. A flood profile may be drawn to show elevation at a given time or crests during a particular flood.

gage height The water-surface elevation referred to some arbitrary gage datum. Gage height is often used interchangeably with the more general term "stage," although gage height is more appropriate when used with a reading on a gage.

high-water mark The highest stage reached by a flood that has been maintained for a sufficient period to leave evidence on the landscape (Benson and Dalrymple, 1967).

recurrence interval (return period) The average interval of time within which the given flood will be equaled or exceeded once. The recurrence interval is directly related to the flood probability. The recurrence interval corresponding to a particular flood probability is equal to 1 divided by the flood probability. For example, a 100-year recurrence interval has a flood probability of 0.01.

streamflow The discharge in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course.

streamgage A site on a stream, canal, lake, or reservoir where systematic observations of stage, discharge, or other hydrologic data are obtained (U.S. Geological Survey, 2011). In this report, when distinguishing between specific types of instrumentation or data used at a streamgage is necessary, the following terms are used: "continuous-record streamgage" is used for the sites where continuous-record data are collected, and "crest-stage gage" is used for the sites where partial-record data are collected.

Appendix 1. High-Water Mark Descriptions

Table 1–1. High-water mark descriptions for the flood of July 2016 in northern Wisconsin and the Bad River Reservation.

[Vertical coordinate data are referenced to the North American Vertical Datum of 1988 (NAVD 88). Horizontal coordinate data are referenced to the North American Datum of 1983 (NAD 83). Approximate quality ratings of high-water marks—Excellent, within plus or minus 0.05 foot; Good, plus or minus 0.10 foot; Fair, plus or minus 0.20 foot; Poor, plus or minus 0.40 foot; and Very Poor, more than 0.40 foot (Koenig and others, 2016). FEV, flood event viewer (U.S. Geological Survey, 2016); RTN–GPS, real-time network global positioning system; RTK–GPS, real-time kinematic; GPS, global positioning system; DEM, digital elevation model]

FEV high-water mark site identifer	River	FEV high-water mark identifier	High-water mark identifier	High-water mark quality	High-water mark description	Latitude	Longitude	Elevation (feet above NAVD 88)	Location and elevation method
17498	Beartrap Creek	16016	BT–103	Excellent	Seed line	46.609126	-90.760340	614.81	RTN–GPS.
17499	Beartrap Creek	16017	BT–36	Very poor	Debris	46.582730	-90.796817	637.07	RTN–GPS.
17499	Beartrap Creek	16018	BT–100	Poor	Mud line	46.582347	-90.797188	638.36	RTN–GPS.
17499	Beartrap Creek	16019	BT–34A	Poor	Mud line	46.582630	-90.797296	639.01	RTN–GPS.
17499	Beartrap Creek	16020	BT–31	Good	Mud line	46.582941	-90.797206	639.66	RTN–GPS.
17500	Beartrap Creek	16021	BT–40	Excellent	Mud line	46.583417	-90.795832	637.91	RTN–GPS.
17500	Beartrap Creek	16022	BT–37B	Excellent	Mud line	46.583212	-90.796098	638.33	RTN–GPS.
17500	Beartrap Creek	16023	BT–39B	Excellent	Mud line	46.583280	-90.795911	638.38	RTN–GPS.
17500	Beartrap Creek	16024	BT–39A	Fair	Mud line	46.583280	-90.795910	638.56	RTN–GPS.
17501	Beartrap Creek	16025	BT–107	Excellent	Scar marks	46.609782	-90.760204	614.52	RTN–GPS.
17501	Beartrap Creek	16026	BT–106	Poor	Seed line	46.609811	-90.760368	614.67	RTN–GPS.
17503	Bad River	16027	BT–13–2	Unknown	Mud line	46.619105	-90.702472	609.22	RTK–GPS with base station.
17504	Bad River	16029	BT–11–2	Unknown	Debris	46.619479	-90.703962	609.14	RTK–GPS with base station.
17504	Bad River	16030	BT–09–3	Unknown	Mud line	46.619476	-90.704298	609.23	RTK–GPS with base station.
17504	Bad River	16031	BT–11A–3	Unknown	Mud line	46.619242	-90.704120	609.30	RTK–GPS with base station.
17504	Bad River	16032	BT–10–3	Unknown	Mud line	46.619439	-90.704380	609.32	RTK–GPS with base station.
17504	Bad River	16033	BT–75–2	Excellent	Mud line	46.613930	-90.697164	610.02	RTK–GPS with base station.
17504	Bad River	16034	BT–75–1	Excellent	Mud line	46.613930	-90.697164	610.02	RTK–GPS with base station.
17504	Bad River	16035	BT–75–3	Excellent	Mud line	46.613930	-90.697164	610.03	RTK–GPS with base station.
17505	Bad River	16036	GS–100–3	Good	Mud line	46.610256	-90.717298	609.92	RTK–GPS with base station.
17506	Bad River	16037	GS–1–2	Fair	Mud line	46.609881	-90.716082	610.33	RTK–GPS with base station.
17507	Bad River	16038	GS–5A–3	Fair	Debris line	46.610618	-90.707368	610.84	RTK–GPS with base station.
17508	Bad River	16039	GS–5–1	Good	Seed line	46.612128	-90.697252	612.35	RTK–GPS with base station.
17509	Bad River	16040	GS–6–6	Excellent	Mud line	46.611783	-90.694968	612.70	RTK–GPS with base station.
17510	Bad River	16041	GS–23–2	Unknown	Mud line	46.611102	-90.691212	612.55	RTK–GPS with base station.
17511	Bad River	16042	GS–10	Poor	Mud line	46.609981	-90.688464	611.61	RTK–GPS with base station.
17511	Bad River	16043	GS–11	Poor	Mud line	46.610153	-90.688423	611.98	RTK–GPS with base station.
17512	Bad River	16044	GS–8–2	Good	Mud line	46.611583	-90.690830	610.58	RTK–GPS with base station.
17513	Bad River	16045	GS–20–2	Excellent	Grass/seed line	46.607145	-90.703797	613.06	RTK–GPS with base station.

Table 1–1. High-water mark descriptions for the flood of July 2016 in northern Wisconsin and the Bad River Reservation.—Continued

[Vertical coordinate data are referenced to the North American Vertical Datum of 1988 (NAVD 88). Horizontal coordinate data are referenced to the North American Datum of 1983 (NAD 83). Approximate quality ratings of high-water marks—Excellent, within plus or minus 0.05 foot; Good, plus or minus 0.10 foot; Fair, plus or minus 0.20 foot; Poor, plus or minus 0.40 foot; and Very Poor, more than 0.40 foot (Koenig and others, 2016). FEV, flood event viewer (U.S. Geological Survey, 2016); RTN–GPS, real-time network global positioning system; RTK–GPS, real-time kinematic; GPS, global positioning system; DEM, digital elevation model]

FEV high-water mark site identifer	River	FEV high-water mark identifier	High-water mark identifier	High-water mark quality	High-water mark description	Latitude	Longitude	Elevation (feet above NAVD 88)	Location and elevation method
17513	Bad River	16046	GS–21–2	Good	Debris	46.607147	-90.703975	613.49	RTK–GPS with base station.
17514	Bad River	16047	GS–3–2	Good	Mud line	46.609178	-90.702694	611.47	RTK–GPS with base station.
17515	Bad River	16048	GS–4P–4	Good	Mud line	46.609010	-90.702297	611.48	RTK–GPS with base station.
17515	Bad River	16049	GS–4–1	Good	Mud line	46.609010	-90.702326	611.93	RTK–GPS with base station.
17516	Bad River	16050	BT–71–3	Excellent	Mud line	46.608696	-90.698668	613.10	RTK–GPS with base station.
17516	Bad River	16051	BT–70–2	Excellent	Mud line	46.608556	-90.698346	613.49	RTK–GPS with base station.
17517	Bad River	16052	BT–7A–6	Unknown	Mud line	46.608243	-90.696505	613.27	RTK–GPS with base station.
17517	Bad River	16053	BT–7–2	Unknown	Debris	46.607967	-90.696239	613.34	RTK–GPS with base station.
17518	Bad River	16054	BT–6–2	Unknown	Mud line	46.609336	-90.694772	612.34	RTK–GPS with base station.
17518	Bad River	16055	BT–15A–1	Unknown	Mud line	46.609870	-90.696168	612.73	RTK–GPS with base station.
17518	Bad River	16056	BT–18–2	Unknown	Mud line	46.609919	-90.695885	612.73	RTK–GPS with base station.
17518	Bad River	16057	BT–5A–3	Unknown	Seed line	46.608900	-90.693491	612.75	RTK–GPS with base station.
17518	Bad River	16058	BT–3–3	Good	Mud line	46.608802	-90.695386	613.13	RTK–GPS with base station.
17518	Bad River	16059	BT–2–2	Unknown	Mud line	46.609452	-90.696558	613.33	RTK–GPS with base station.
17518	Bad River	16061	BT–16A–2	Unknown	Mud line	46.609743	-90.696292	613.48	RTK–GPS with base station.
17518	Bad River	16062	BT–4–3	Good	Mud line	46.608779	-90.695268	613.74	RTK–GPS with base station.
17521	Bad River	16064	BT–72–2	Excellent	Mud line	46.608429	-90.692253	612.31	RTK–GPS with base station.
17522	Bad River	16065	BT–73–3	Excellent	Seed line	46.608441	-90.690265	612.51	RTK–GPS with base station.
17523	Bad River	16066	BT–74A–1	Unknown	Mud line	46.608313	-90.684218	611.97	RTK–GPS with base station.
17524	Bad River	16067	BT–74–2	Excellent	Mud line	46.608169	-90.684024	612.15	RTK–GPS with base station.
17525	Bad River	16068	GS–13–3	Fair	Mud line	46.609602	-90.682583	611.39	RTK–GPS with base station.
17526	Bad River	16069	GS–17–3	Good	Mud line	46.607148	-90.677168	610.33	RTK–GPS with base station.
17527	Bad River	16070	GS–16A–3	Excellent	Mud line	46.606837	-90.677397	611.42	RTK–GPS with base station.
17527	Bad River	16071	GS–16B–1	Excellent	Seed line	46.606773	-90.677275	611.63	RTK–GPS with base station.
17528	Bad River	16072	GS–14–2	Good	Mud line	46.605087	-90.679687	611.59	RTK–GPS with base station.
17529	Bad River	16073	GS–15–3	Fair	Mud line	46.604598	-90.679272	611.76	RTK–GPS with base station.
17530	Bad River	16074	BT–81–1	Fair-poor	Mud line	46.598371	-90.690787	618.15	RTK–GPS with base station.
17530	Bad River	16075	GS–46	Fair	Mud line	46.597470	-90.689553	618.79	Hand-held GPS location overlain on Ashland County DEM.
17531	Bad River	16076	BT–80–2	Fair-poor	Mud line	46.599206	-90.689975	615.86	RTK–GPS with base station.
17531	Bad River	16077	GS–50	Good	Mud line	46.599700	-90.690373	616.61	Hand-held GPS location overlain on Ashland County DEM.

Table 1–1. High-water mark descriptions for the flood of July 2016 in northern Wisconsin and the Bad River Reservation.—Continued

[Vertical coordinate data are referenced to the North American Vertical Datum of 1988 (NAVD 88). Horizontal coordinate data are referenced to the North American Datum of 1983 (NAD 83). Approximate quality ratings of high-water marks—Excellent, within plus or minus 0.05 foot; Good, plus or minus 0.10 foot; Fair, plus or minus 0.20 foot; Poor, plus or minus 0.40 foot; and Very Poor, more than 0.40 foot (Koenig and others, 2016). FEV, flood event viewer (U.S. Geological Survey, 2016); RTN–GPS, real-time network global positioning system; RTK–GPS, real-time kinematic; GPS, global positioning system; DEM, digital elevation model]

FEV high-water mark site identifer	River	FEV high-water mark identifier	High-water mark identifier	High-water mark quality	High-water mark description	Latitude	Longitude	Elevation (feet above NAVD 88)	Location and elevation method
17532	Bad River	16078	BT–82–3	Fair-poor	Mud line	46.599331	-90.688725	617.98	RTK–GPS with base station.
17533	Bad River	16079	BT–44–3	Good	Debris	46.600409	-90.689413	615.97	RTK–GPS with base station.
17533	Bad River	16080	BT–45–2	Good	Debris	46.600476	-90.689508	615.98	RTK–GPS with base station.
17533	Bad River	16081	BT–41A–1	Unknown	Mud line	46.600029	-90.689113	616.05	RTK–GPS with base station.
17533	Bad River	16082	GS–49	Fair	Grass/debris	46.600310	-90.689433	616.61	Hand-held GPS location overlain on Ashland County DEM.
17534	Bad River	16083	BT–83–1	Good	Mud line	46.603767	-90.656633	618.93	RTK–GPS with base station.
17535	Denomie Creek	16084	BT–84–2	Poor	Mud line	46.602424	-90.656039	618.00	RTK–GPS with base station.
17536	Denomie Creek	16085	BT–25–A–3	Unknown	Debris	46.602030	-90.649616	625.20	RTK–GPS with base station.
17537	Denomie Creek	16086	BT–87–2	Poor	Seed line	46.601421	-90.652109	624.48	RTK–GPS with base station.
17538	Denomie Creek	16087	BT–86–4	Poor	Mud line	46.601258	-90.651453	624.57	RTK–GPS with base station.
17538	Denomie Creek	16088	BT–88–1	Poor	Debris	46.601276	-90.652439	624.58	RTK–GPS with base station.
17538	Denomie Creek	16089	BT–85–2	Poor	Mud line	46.601258	-90.652007	624.93	RTK–GPS with base station.
17539	Denomie Creek	16090	BT–27A–2	Poor	Mud line	46.600220	-90.651215	624.73	RTK–GPS with base station.
17539	Denomie Creek	16091	BT–29–1	Unknown	Debris	46.600111	-90.651253	624.81	RTK–GPS with base station.
17539	Denomie Creek	16092	BT–27–2	Good	Mud line	46.600415	-90.651346	625.22	RTK–GPS with base station.
17539	Denomie Creek	16093	BT–30B–2	Fair	Mud line	46.600111	-90.651253	625.74	RTK–GPS with base station.
17539	Denomie Creek	16094	BT–30–1	Poor	Debris	46.600111	-90.651253	625.90	RTK–GPS with base station.
17540	Denomie Creek	16095	BT–50–1	Fair	Debris	46.595398	-90.656025	632.74	RTK–GPS with base station.
17541	Denomie Creek	16096	BT–19–2	Fair	Mud line	46.594436	-90.654115	631.86	RTK–GPS with base station.
17542	Denomie Creek	16097	BT–50A–5	Very poor	Debris	46.594655	-90.655604	634.88	RTK–GPS with base station.
17543	Denomie Creek	16098	BT–57–2	Fair	Mud line	46.593749	-90.654922	634.86	RTK–GPS with base station.
17544	Denomie Creek	16099	BT–50A–3	Very poor	Debris	46.594441	-90.655376	636.98	RTK–GPS with base station.
17545	Bad River	16100	GS–XS–26–2	Good	Debris line	46.487387	-90.698162	694.62	RTN–GPS\total station.
17545	Bad River	16101	GS–XS–26–3	Excellent	Mud line	46.487763	-90.698297	694.91	RTN–GPS\total station.
17546	Bad River	16102	GS–XS–26–1	Unknown	Mud line	46.486713	-90.698278	695.62	RTN–GPS\total station.
17547	Bad River	16103	GS–31	Fair	Mud/debris	46.499890	-90.693593	688.93	Hand-held GPS location overlain on Ashland County DEM.
17548	Bad River	16104	GS–32	Poor	Debris	46.501230	-90.692853	687.87	Hand-held GPS location overlain on Ashland County DEM.
17549	Bad River	16105	GS–33	Poor	Grass/debris	46.502720	-90.692323	683.25	Hand-held GPS location overlain on Ashland County DEM.
17550	Bad River	16106	GS–34	Good	Mud line	46.518800	-90.694013	636.00	Hand-held GPS location overlain on Ashland County DEM.
17551	Bad River	16107	GS–35	Good	Mud line	46.523650	-90.699933	634.34	Hand-held GPS location overlain on Ashland County DEM.

Table 1–1. High-water mark descriptions for the flood of July 2016 in northern Wisconsin and the Bad River Reservation.—Continued

[Vertical coordinate data are referenced to the North American Vertical Datum of 1988 (NAVD 88). Horizontal coordinate data are referenced to the North American Datum of 1983 (NAD 83). Approximate quality ratings of high-water marks—Excellent, within plus or minus 0.05 foot; Good, plus or minus 0.10 foot; Fair, plus or minus 0.20 foot; Poor, plus or minus 0.40 foot; and Very Poor, more than 0.40 foot (Koenig and others, 2016). FEV, flood event viewer (U.S. Geological Survey, 2016); RTN–GPS, real-time network global positioning system; RTK–GPS, real-time kinematic; GPS, global positioning system; DEM, digital elevation model]

FEV high-water mark site identifer	River	FEV high-water mark identifier	High-water mark identifier	High-water mark quality	High-water mark description	Latitude	Longitude	Elevation (feet above NAVD 88)	Location and elevation method
17552	Bad River	16108	GS–36	Good	Mud line	46.528610	-90.693113	633.43	Hand-held GPS location overlain on Ashland County DEM.
17553	Bad River	16109	GS–37	Good	Mud line	46.531370	-90.704353	630.86	Hand-held GPS location overlain on Ashland County DEM.
17554	Bad River	16110	GS–38	Good	Mud line	46.540200	-90.707363	631.10	Hand-held GPS location overlain on Ashland County DEM.
17555	Bad River	16111	GS–39	Good	Mud line	46.547600	-90.705143	629.29	Hand-held GPS location overlain on Ashland County DEM.
17556	Bad River	16112	GS–40	Good	Mud line	46.551810	-90.694703	627.55	Hand-held GPS location overlain on Ashland County DEM.
17557	Bad River	16113	GS–41	Good	Mud line	46.556830	-90.690533	627.08	Hand-held GPS location overlain on Ashland County DEM.
17558	Bad River	16114	GS–42	Good	Mud line	46.560800	-90.679783	627.84	Hand-held GPS location overlain on Ashland County DEM.
17559	Bad River	16115	GS–43	Good	Mud line	46.570170	-90.688153	624.37	Hand-held GPS location overlain on Ashland County DEM.
17560	Bad River	16116	GS–44	Good	Mud line	46.575870	-90.675433	622.71	Hand-held GPS location overlain on Ashland County DEM.
17561	Bad River	16117	GS–51	Good	Mud line	46.601340	-90.698163	615.88	Hand-held GPS location overlain on Ashland County DEM.
17562	Bad River	16118	GS–52	Fair	Mud line	46.602250	-90.698053	615.04	Hand-held GPS location overlain on Ashland County DEM.
17565	Bad River	16120	GS–53	Fair	Mud line	46.601820	-90.701133	616.09	Hand-held GPS location overlain on Ashland County DEM.
17566	Bad River	16122	GS–54	Fair	Mud line	46.604160	-90.700923	615.12	Hand-held GPS location overlain on Ashland County DEM.
17567	Bad River	16123	GS–55	Fair	Mud line	46.604580	-90.703973	613.37	Hand-held GPS location overlain on Ashland County DEM.
17570	Bad River	16125	GS–XS–27–2	Good	Mud line	46.611930	-90.683458	609.32	RTN–GPS\total station.
17571	Bad River	16127	GS–XS–25–2	Excellent	Mud line	46.523152	-90.680344	640.35	RTN–GPS\total station.
17571	Bad River	16128	GS–XS–25–3	Excellent	Mud line	46.523182	-90.680260	640.88	RTN–GPS\total station.
17571	Bad River	16130	GS–XS–25–1	Unknown	Debris line	46.523134	-90.680392	641.45	RTN–GPS\total station.
18574	Denomie Creek	17163	BT–24	Unknown	Debris	46.605279	-90.649377	629.59	Hand-held GPS location overlain on Ashland County DEM.

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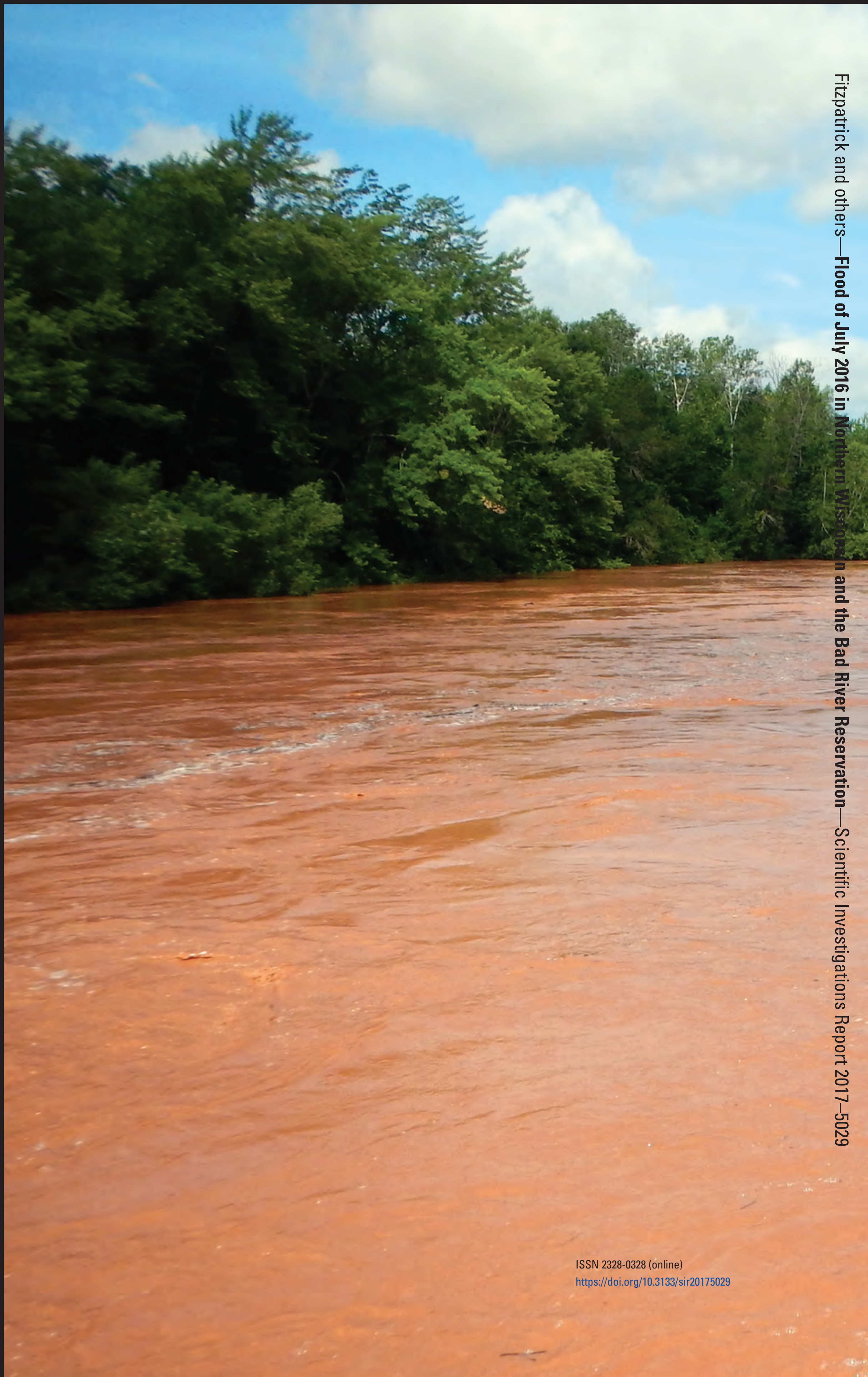

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