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Water-Surface Profile Maps for the Mississippi River near Prairie Island, Minnesota, 2019

Scientific Investigations Report 2021–5018

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

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U.S. Geological Survey, 2019, USGS water data for the Nation: U.S. Geological Survey National Water Information System database, https://doi.org/10.5066/F7P55KJN.

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	0.0929	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Hydraulic gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)

Datum

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

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

Abbreviations

DEM	digital elevation model
GIS	geographic information system
lidar	light detection and ranging
NWS	National Weather Service
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey

Water-Surface Profile Maps for the Mississippi River near Prairie Island, Minnesota, 2019

By Aliesha L. Krall and Julia G. Prokopec

Abstract

Digital water-surface profile maps for a 14-mile reach of the Mississippi River near Prairie Island, Minnesota, from the confluence of the St. Croix River at Prescott, Wisconsin, to upstream from the U.S. Army Corps of Engineers Lock and Dam No. 3 (U.S. Army Corps of Engineers National Inventory of Dams number MN00595) in Welch, Minnesota, were created by the U.S. Geological Survey (USGS) in cooperation with the Prairie Island Indian Community in the State of Minnesota. The water-surface profile maps depict estimates of the areal extent and depth of water inundation corresponding to selected water levels (stages) at the USGS streamgage Mississippi River at Prescott, Wisconsin (USGS station number 05344500). Current conditions for estimating near-real-time areas of inundation by use of USGS streamgage information may be obtained from the National Water Information System on the internet at https://doi.org/10.5066/F7P55KJN.

In this study, water-surface profiles were computed for the stream reach by means of a one-dimensional step-backwater model. The model was calibrated by using the most current stage-discharge relations at the USGS streamgage Mississippi River at Prescott, Wisconsin (USGS station number 05344500). The hydraulic model was then used to determine four water-surface profiles for stream stages at 37.00, 39.00, 40.00, and 41.00 feet (ft) referenced to the streamgage datum and ranging from bankfull to approximately 2 ft below the highest recorded stage at the streamgage, which is 43.11 ft. The simulated water-surface profiles were then combined with a geographic information system digital elevation model (derived from light detection and ranging data having a 0.35-ft vertical and 1.97-ft root mean square error horizontal resolution) in order to delineate the area inundated at each stage.

The combination of maps provided in this report and real-time stage data from the upstream USGS streamgage provide emergency management personnel and residents with information that is critical for flood response activities such as evacuations and road closures as well as for post flood recovery efforts.

Introduction

Prairie Island is a small urban community located in Welch, Minnesota, with an estimated population of approximately 350–400 people, 326 of which are members of the Prairie Island Indian Community in the State of Minnesota (hereafter referred to as "Prairie Island Indian Community") (L. Charles, Prairie Island Indian Community, written commun., 2019). Prairie Island has experienced numerous severe floods, most notably in 1965, 1969, 1997, and 2001. Most of the flood damages have been caused by the Mississippi River along the northeast side of Prairie Island. The Vermillion River flows around the southwest side of the Prairie Island. Flood plains within Prairie Island are moderately developed and contain a mix of agricultural fields, residential and commercial structures, and a nuclear powerplant.

Prior to this study, the Prairie Island Indian Community officials relied on several information sources to decide how to best alert the public and mitigate flood damages, and all of these sources are available on the internet. Their primary sources of information are the U.S. Geological Survey (USGS) streamgage Mississippi River at Prescott, Wisconsin (USGS station number 05344500; U.S. Geological Survey, 2019; hereafter referred to as "USGS streamgage 05344500"), and the U.S. Army Corps of Engineers (USACE) streamgage Mississippi River at Lock and Dam No. 3 (USACE National Inventory of Dams number MN00595), from which current or historical water levels (stage) can be obtained. Current stage data from USGS streamgage 05344500 are particularly useful for residents in the immediate vicinity of the streamgage but are of limited use to residents farther upstream or downstream because the water-surface elevation is not constant along the entire stream channel. Also, the Federal Emergency Management Agency (FEMA) and State emergency management mitigation teams or property owners typically lack information related to how deep the water is at locations other than near USGS streamgages.

Purpose and Scope

The purpose of this report is to describe how a series of estimated water-surface profile maps were developed for the Mississippi River near Prairie Island in Welch, Minn., using an existing USACE hydraulic model. Within this report, maps and other useful water-surface elevation information are available. Four stage elevations have been selected to estimate water-surface profile maps for Prairie Island that correspond to the USGS streamgage 05344500 (table 1). The maps and depth grids information are available as a USGS data release from ScienceBase (Krall and Prokopec, 2022). The scope of the study was limited to the Mississippi River starting downstream from the confluence of the St. Croix River in Prescott, Wis., and ending upstream from the USACE Lock and Dam No. 3 in Welch, Minn. (fig. 1). Tasks specific to development of the maps were (1) obtain USACE one-dimensional HEC–RAS hydraulic model in the study area, (2) verify energy-loss factors (roughness coefficients) in the stream channel and flood plain and compile steady-flow data from USACE model runs, (3) compute water-surface profiles by use of the USACE HEC–RAS computer program (U.S. Army Corps of Engineers, 2016a), (4) produce estimated water-surface profile maps at various stream stages by use of the USACE HEC–GeoRAS computer program (U.S. Army Corps of Engineers, 2009) in a geographic information system (GIS), and (5) publish the estimated water-surface profile maps and depth grids as a USGS data release (Krall and Prokopec, 2022).

Methods used to create maps presented in this report are generally cited from previously published reports. If techniques varied substantially from previously documented methods because of local hydrologic conditions or availability of data, they are described in detail in this report. Maps were produced for water levels referenced to the stream stages of 37.00, 39.00, 40.00, and 41.00 ft at USGS streamgage 05344500 (figs. 2–5).

Study Area Description

The Mississippi River near Prairie Island is located in southeastern Minnesota in the Central Lowlands (Fenneman and Johnson, 1946). Prairie Island is a 9.5-square mile (mi^2) island just 14 miles (mi) northwest of Red Wing, Minn., and 30 mi southeast of St. Paul, Minn. Interconnected lakes and wetlands surround Prairie Island, the Mississippi River runs along the northeast, and the Vermillion River runs along the southwest side of the island. The drainage area ranges from 44,800 mi^2 at the USGS streamgage 05344500 upstream from Prairie Island and just downstream (200 ft) from the confluence of the St. Croix River into the Mississippi River, to 44,900 mi^2 at the USACE Lock and Dam No. 3 at the downstream extent of the study reach. The headwaters of the Mississippi River originate in Clearwater County, and the stream flows generally southeastward for roughly 300 river miles before reaching Prairie Island. The St. Croix River, a major tributary to the Mississippi River, joins the main stem as it flows through Prescott, Wis., just upstream from Prairie Island.

The Prairie Island terrain is generally flat. The study reach is approximately 14 mi long. About 45 percent of the land contiguous to the study reach is classified as urban or developed, 1 percent as forest, 16 percent as cropland, 33 percent as wetlands, and 6 percent as barren land (Minnesota Department of Natural Resources, 2014). The main channel within the study reach does not have any road crossings or other structures that lie within the channel or the adjacent flood plain. The Prairie Island flood plain contains agricultural land, residential and commercial structures, and a nuclear powerplant.

Table 1. U.S. Geological Survey (USGS) streamgage information on the Mississippi River at Prescott, Wisconsin (USGS station number 05344500). (Data from U.S. Geological Survey, 2019.)

[mi^2, square mile; ft, foot; ft^3/s, cubic foot per second; NAVD 88, North American Vertical Datum of 1988]

Station name	Station number	Drainage area (mi^2)	Latitude	Longitude	Period of record	Maximum recorded stage at gage (ft) and date	Maximum discharge (ft^3/s) and date	Gage datum (ft above NAVD 88)
Mississippi River at Prescott, Wisconsin	05344500	44,800	44°44’45”	92°48’00”	June 1928 to 2019	43.11, April 15, 1965	228,000, April 15, 1965	649.67

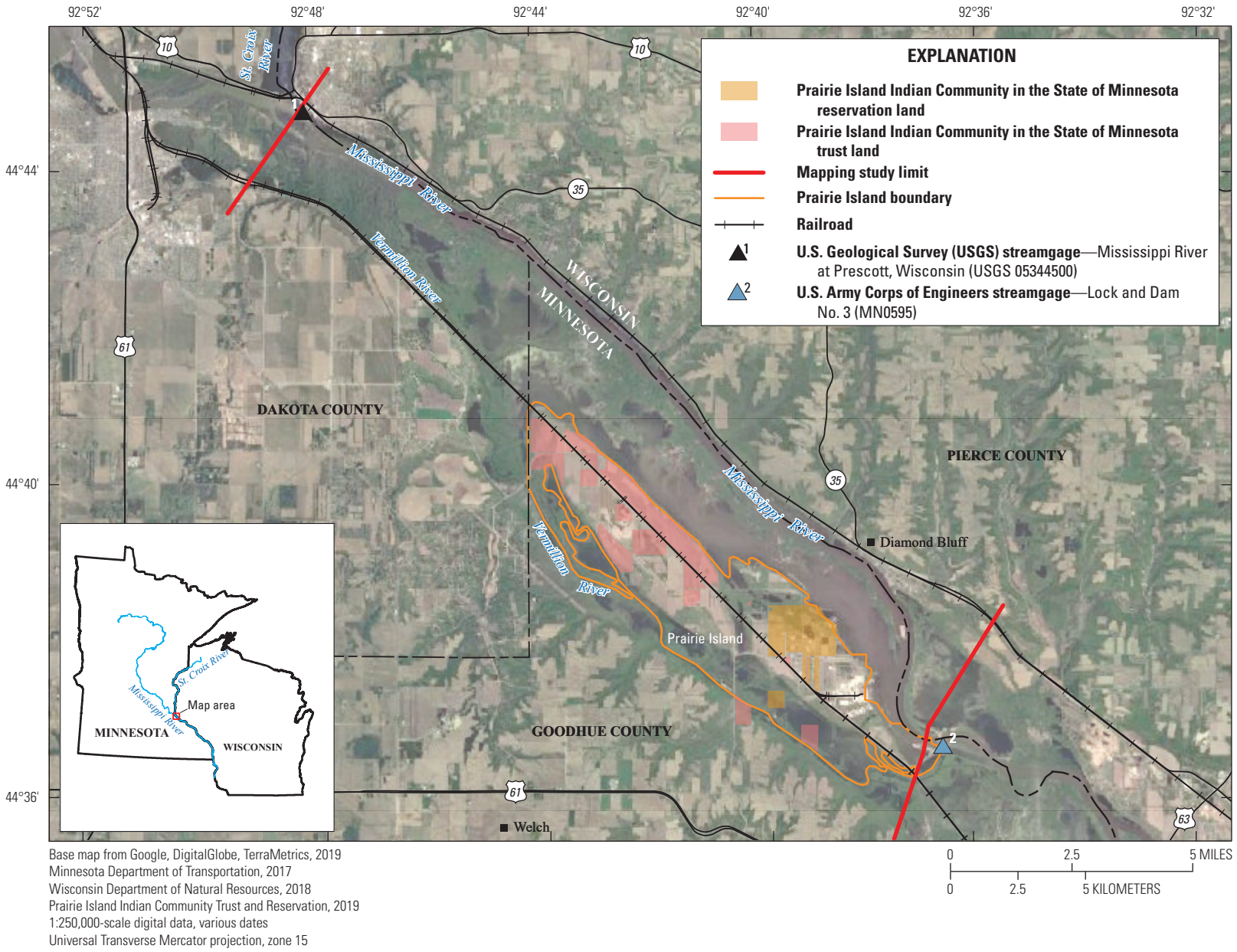


Figure 1. Location and extent of the water-surface mapping reach for the Mississippi River near Prairie Island in the State of Minnesota at the confluence of the St. Croix River at the U.S. Geological Survey (USGS) streamgage on the Mississippi River at Prescott, Wisconsin (USGS station number 05344500), to upstream from the U.S. Army Corps of Engineers (USACE) streamgage on the Mississippi River at Lock and Dam No. 3 (USACE National Inventory of Dams number MN00595), Welch, Minnesota.

Previous Studies

The current flood insurance study for Prairie Island Indian Community (Federal Emergency Management Agency, 2009) was published in 2009. That study provided information on the 1.0- and 0.2-percent annual exceedance probability water-surface profiles and associated flood-plain maps for the Mississippi River in Goodhue County, Minn. Estimates of the peak discharges for the 1.0-percent annual exceedance probability flood along the Mississippi River were based on a 2002 USACE Upper Mississippi River Floodway Computation study (Federal Emergency Management Agency, 2009).

The model input used to create water-surface profile maps for this study was modified from a previously published model from the USACE Mississippi River Valley Division, St. Paul District (U.S. Army Corps of Engineers, 2018). This includes channel bathymetry, light detection and ranging (lidar), and model geometry. Modeled areas and flow hydrographs developed by the USACE for river sections upstream and downstream from the study area were not included in this study; however, calibration results from the USACE study were used as calibration in this study.

Constructing Water-Surface Profiles

The water-surface profiles used to produce the four maps in this study were computed by using HEC–RAS, version 5.0.3 (U.S. Army Corps of Engineers, 2016a). HEC–RAS is a one- or two-dimensional step-backwater model for simulation of water-surface profiles with gradually varied, steady-state (or unsteady-state) flow computation options. The HEC–RAS analysis for this study was done by using the one-dimensional steady-state flow computation option. Input and output files from the HEC–RAS modeling are available in Krall and Prokopec (2022).

Hydrologic and Steady-Flow Data

The study area hydrologic network consists of a streamgage (USGS streamgage 05344500; fig. 1; table 1) with a period of record from June 1928 to June 2019 (U.S. Geological Survey, 2019). Stream stage is measured continuously at the site, and continuous records of streamflow are computed. All water-surface elevations are referenced to the North American Vertical Datum of 1988. The streamgage is equipped with satellite radio transmitters that allow data to be transmitted routinely on the Internet within an hour of collection. Measurements made during periods of moderate to high flow were used for hydrologic model calibration of the streamgage.

Steady-flow data consisted of flow regime, boundary conditions (either known stage associated with a streamflow measurement, critical depth, normal depth, or streamgage rating-curve value), and peak-discharge information. The steady-flow data for the study reach were obtained from previous studies and field measurements of streamflow at USGS streamgage 05344500 (U.S. Army Corps of Engineers, 2016b; U.S. Geological Survey, 2019). All computations were based on streamflow values with known stages from actual streamflow measurements or stage-discharge relations.

Topographic/Bathymetric Data

The HEC–RAS model was obtained from the USACE in 2018 for this study (U.S. Army Corps of Engineers, 2018). Topographic and continuous bathymetric data (topobathy) were already in the model. Channel cross sections were developed from topobathy surveys collected by USACE in 2008–09 (U.S. Army Corps of Engineers, 2016b). These cross sections provide detailed channel-elevation data below the water surface and were collected by using hydroacoustic instrumentation to measure depth and Differential Global Positioning System instrumentation to determine horizontal position. Lidar data were used to provide digital elevation data for the portions of the cross sections that were above the water surface at the time of the surveys. The lidar data were collected in 2011–12 by the Minnesota Department of Natural Resources (Minnesota Department of Natural Resources, 2011).

Various man-made drainage structures (bridges, culverts, roadway embankments, levees, and dams) in and along the river affect or have the potential to affect water-surface elevations during river flooding. In the study area, there are no structures over the Mississippi River. The most downstream cross-section is directly upstream from USACE Lock and Dam No. 3. Dam structure and dam operations scenarios affecting stage-flow relation were not accounted for in the model.

Energy-Loss Factors

Field observations and high-resolution aerial photographs were used to select initial (pre-calibration) Manning's roughness coefficients ("*n*" values) for energy-loss (friction-loss) calculations. The final Manning's *n* values used are 0.025 for the main channel and 0.07 to 0.10 for the overbank areas simulated in this analysis.

Model Calibration and Performance

The initial hydraulic model by USACE was calibrated to two unsteady flow events from Lock and Dam Pool No. 2, not shown in figure 1, from an October 2018 event and compared to an October 2017 event. The October 2018 model calibration ranged from 48,900 cubic feet per second (ft^3/s) to the estimated peak flow of 129,400 ft^3/s. A simplified extreme event calibration from 1,500 to 247,000 ft^3/s covered a larger spectrum of flows and was compared to the October 2017

event (U.S. Army Corps of Engineers, 2016b). The model was calibrated by adjusting Manning's *n* values and, in some cases, changing the channel cross section or slope until the results of the hydraulic computations closely agreed with known flood-discharge and stage values. Differences between measured and simulated stream stage for measured or rated flows at USGS streamgage 05344500 ranged from 0.59 to 0.72 ft. The results demonstrate that the model is capable of simulating accurate stream stage over a wide range of flows in the basin. Details on techniques used in model development and calibration can be found in Bales and others (2007).

Development of Water-Surface Profiles

Profiles were developed for a total of four stream stages at 1- to 2-ft intervals between 37.00 and 41.00 ft as referenced to USGS streamgage 05344500. Discharges corresponding to the various stages were obtained from the most current stage-discharge relation (USGS rating no. 49) at USGS streamgage 05344500 (table 2).

Water-Surface Profile Mapping

Water-surface profile maps were created for USGS streamgage 05344500 using a USACE HEC–RAS model published by USACE St. Paul District (figs. 2–5; U.S. Army Corps of Engineers, 2018). The maps were created in a GIS by combining the water-surface profiles and digital elevation model (DEM) data. The DEM data were derived from 1.97 ft root mean square error horizontal resolution lidar data with a vertical accuracy of 0.35 ft. Estimated inundation boundaries for each simulated profile were developed with HEC–GeoRAS software (U.S. Army Corps of Engineers, 2009). HEC–GeoRAS is a set of procedures, tools, and utilities for processing geospatial data in ArcGIS by using a graphical user interface (Whitehead and Ostheimer, 2009). The maps show estimated water-inundated areas overlaid on high-resolution, georeferenced aerial photographs of the study area for each of the water-surface profiles that were generated by the hydraulic model. Areas of known water, such as ponds, were kept in the inundation mapping and not removed. Additional areas such as flow through culverts or other low-lying areas of inundation were also kept based on review from aerial imagery.

Mississippi River, Minnesota Water-Surface Profile Maps Availability Online

The water-surface profile maps and current study documentation are available as a USGS data release (Krall and Prokopec, 2022) as shapefiles (.shp) and Keyhole Markup Zipped files (.kmz) that can be opened using Esri GIS systems (.shp file) or Google Earth (.kmz file). The estimated water-surface profile maps are displayed in sufficient detail to note the extent of water inundation with respect to individual structures so that preparations for flooding and decisions for emergency response can be performed efficiently. Roadways and bridges were closely reviewed and are shown as shaded (inundated and likely impassable) or not shaded (dry and passable) to facilitate emergency planning and use. However, buildings that are shaded do not reflect water inundation but denote that bare-earth surfaces near the buildings are inundated. When the water depth adjacent to the building of interest exceeds that building's height, the structure can be considered fully submerged.

Disclaimer for Water-Surface Profile Maps

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

Table 2. Calibration of model to target water-surface elevations at U.S. Geological Survey (USGS) streamgage on the Mississippi River at Prescott, Wisconsin (USGS station number 05344500).

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

Stage of water-surface profile (ft)	Discharge (ft^3/s)	Target water-surface elevation (ft NAVD 88)	Simulated water-surface elevation (ft NAVD 88)	Difference in elevation (ft)
37.00	122,100	686.67	686.08	−0.59
39.00	153,300	688.67	688.04	−0.63
40.00	170,200	689.67	689.01	−0.66
41.00	188,000	690.67	689.95	−0.72

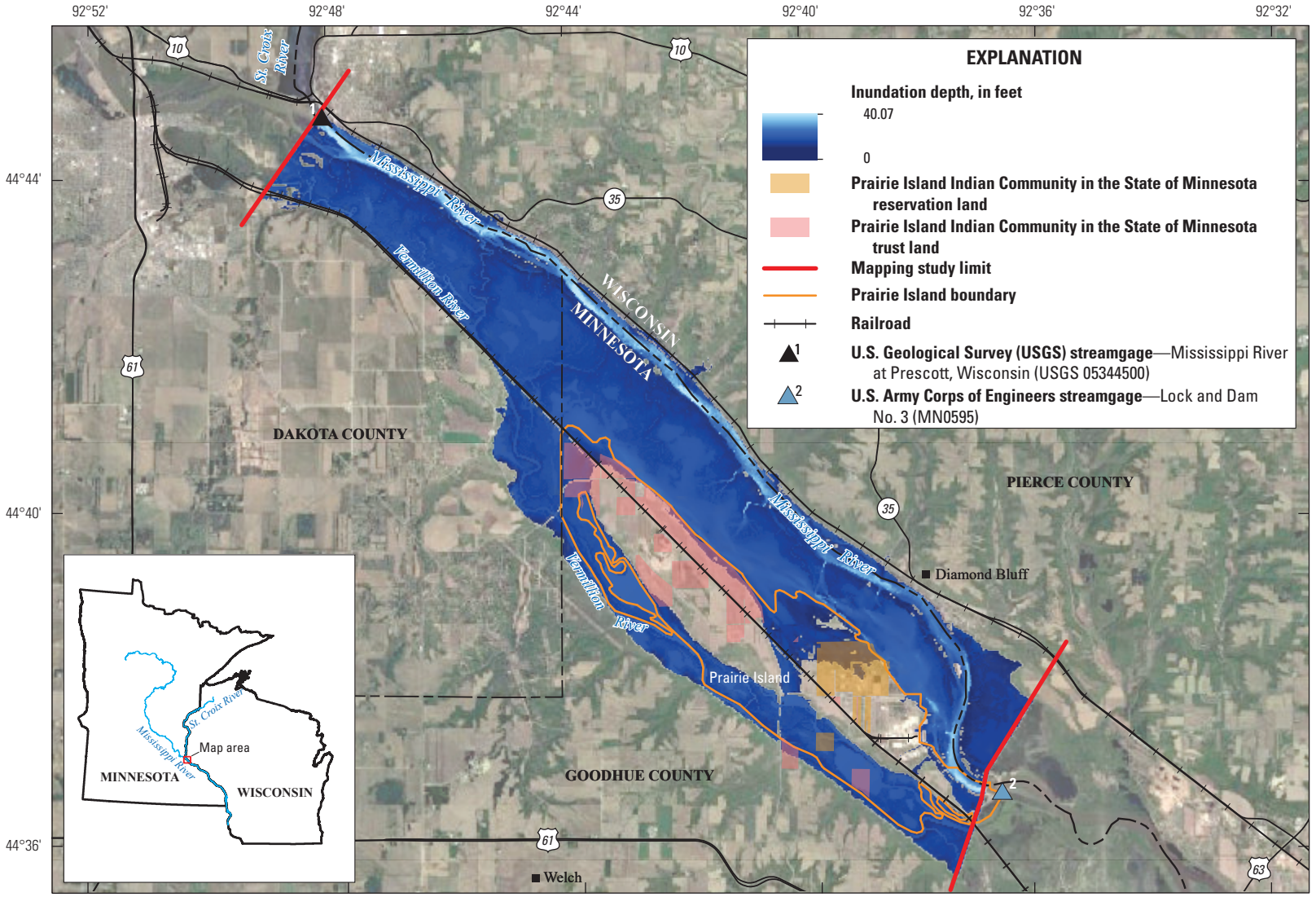
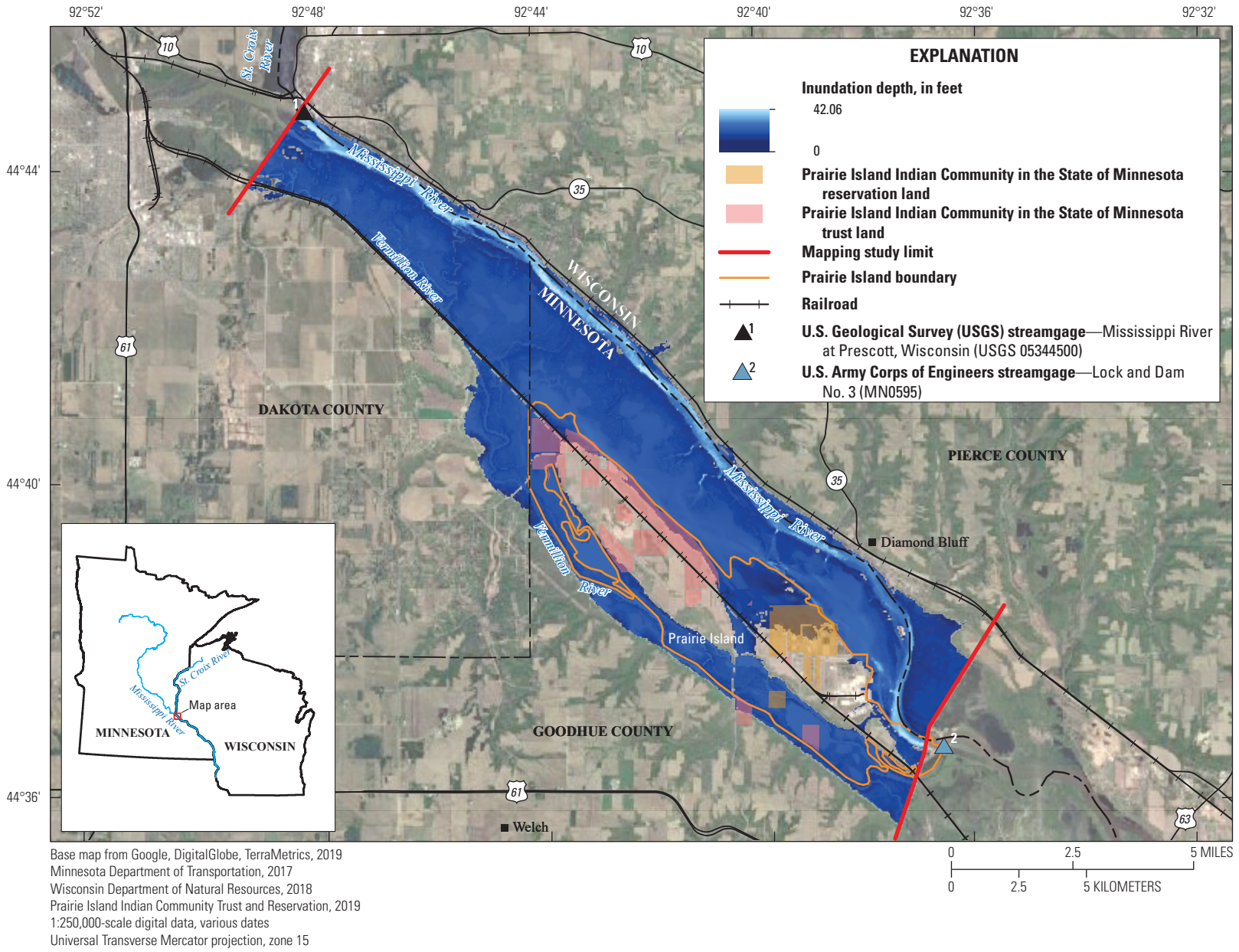


Figure 2. Depth and extent of water inundation for the Mississippi River near Prairie Island in the State of Minnesota at the confluence of the St. Croix River at the U.S. Geological Survey (USGS) streamgage on the Mississippi River at Prescott, Wisconsin (USGS station number 05344550), to upstream from the U.S. Army Corps of Engineers (USACE) streamgage on the Mississippi River at Lack and Dam No. 3 (USACE National Inventory of Dams number MN00595), Welch, Minnesota, at a water-level stage of 37.00 feet.



Base map from Google, DigitalGlobe, TerraMetrics, 2019
Minnesota Department of Transportation, 2017
Wisconsin Department of Natural Resources, 2018
Prairie Island Indian Community Trust and Reservation, 2019
1:250,000-scale digital data, various dates
Universal Transverse Mercator projection, zone 15

Figure 3. Depth and extent of water inundation for the Mississippi River near Prairie Island in the State of Minnesota at the confluence of the St. Croix River at the U.S. Geological Survey (USGS) streamgage on the Mississippi River at Prescott, Wisconsin (USGS station number 05344550), to upstream from the U.S. Army Corps of Engineers (USACE) streamgage on the Mississippi River at Lack and Dam No. 3 (USACE National Inventory of Dams number MN00595), Welch, Minnesota, at a water-level stage of 39.00 feet.

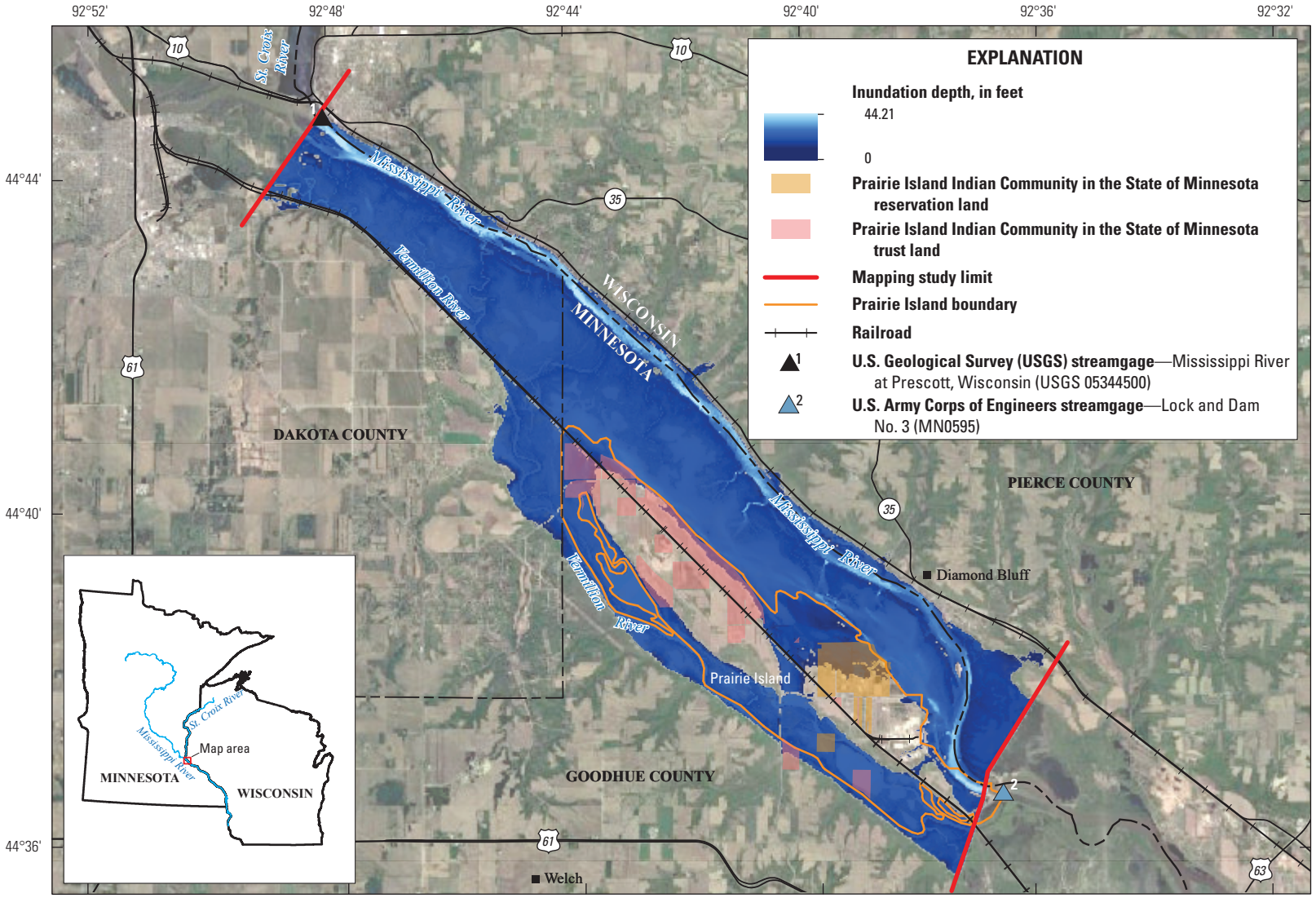


Figure 4. Depth and extent of water inundation for the Mississippi River near Prairie Island in the State of Minnesota at the confluence of the St. Croix River at the U.S. Geological Survey (USGS) streamgage on the Mississippi River at Prescott, Wisconsin (USGS station number 05344550), to upstream from the U.S. Army Corps of Engineers (USACE) streamgage on the Mississippi River at Lack and Dam No. 3 (USACE National Inventory of Dams number MN00595), Welch, Minnesota, at a water-level stage of 40.00 feet.

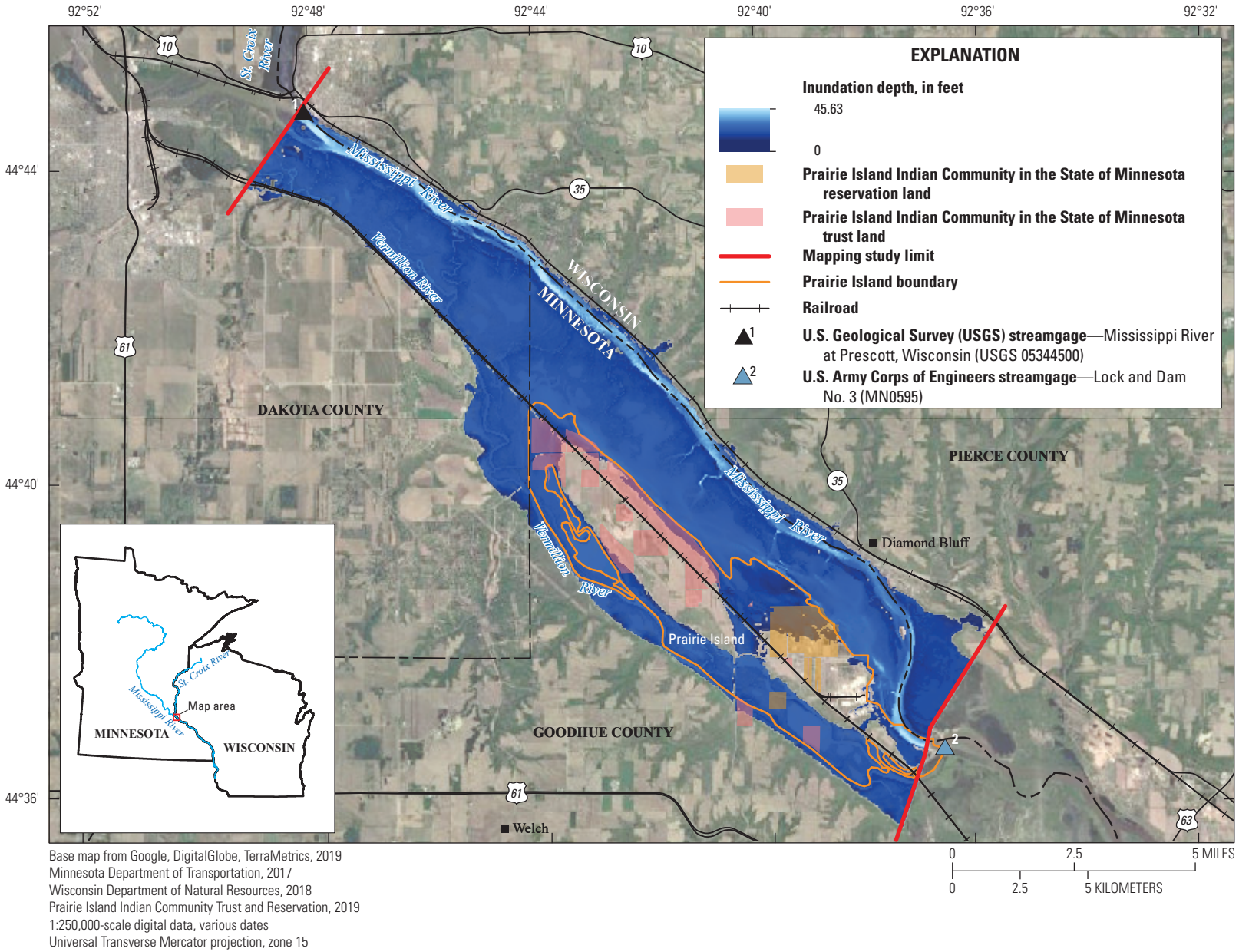


Figure 5. Depth and extent of water inundation for the Mississippi River near Prairie Island in the State of Minnesota at the confluence of the St. Croix River at the U.S. Geological Survey (USGS) streamgage on the Mississippi River at Prescott, Wisconsin (USGS station number 05344550) to upstream from the U.S. Army Corps of Engineers (USACE) streamgage on the Mississippi River at Lack and Dam No. 3 (USACE National Inventory of Dams number MN00595), Welch, Minnesota, at a water-level stage of 41.00 feet.

Uncertainties and Limitations Regarding Use of Water-Surface Profile Maps

Although the water-surface profile maps represent the boundaries of water-inundated areas with a distinct line, some uncertainty is associated with these maps. The inundation boundaries shown were estimated based on stream stages and streamflows at the selected USGS streamgage 05344500. Water-surface elevations along the river reach were estimated by steady-state hydraulic modeling, assuming unobstructed flow, and using streamflows and hydrologic conditions anticipated at USGS streamgage 05344500. The hydraulic model reflects any bridge, dam, levee, or other hydraulic structures existing as of June 2019. Unique meteorological factors (timing and distribution of precipitation) may cause actual streamflows along the modeled reach to vary from those assumed during a flood, which may lead to deviations in the water-surface elevations and inundation boundaries shown. Additional areas may be inundated owing to unanticipated conditions such as changes in the streambed elevation or roughness, backwater into major tributaries along a main-stem river, or backwater from localized debris or ice jams. The accuracy of the floodwater extent portrayed on these maps will vary with the accuracy of the DEM used to simulate the land surface. Additional uncertainties and limitations pertinent to this study may be described elsewhere in this report.

If this series of water-surface profile maps will be used in conjunction with National Weather Service (NWS) river forecasts, the user should be aware of additional uncertainties that may be inherent or factored into NWS forecast procedures. The NWS uses forecast models to estimate the quantity and timing of water flowing through selected stream reaches in the United States. These forecast models (1) estimate the amount of runoff generated by precipitation and snowmelt, (2) simulate the movement of floodwater as it proceeds downstream, and (3) predict the flow and stage (and water-surface elevation) for the stream at a given location (Advanced Hydrologic Prediction Service (AHPS) forecast point) throughout the forecast period (every 6 hours and 3 to 5 days out in many locations). For more information on AHPS forecasts, please see: https://water.weather.gov/ahps/pcpn_and_river_forecasting.pdf.

Summary

Estimated water-surface profile maps were developed by the U.S. Geological Survey (USGS) in cooperation with the Prairie Island Indian Community in the State of Minnesota for the Mississippi River near Prairie Island from the confluence of the St. Croix River at Prescott, Wisconsin, to upstream from the U.S. Army Corps of Engineers Lock and Dam No. 3 (U.S. Army Corps of Engineers National Inventory of Dams number MN00595) in Welch, Minnesota. These maps, in conjunction with the real-time stage data from USGS streamgage 05344500, will help to guide the general public in taking individual safety precautions and will provide the Prairie Island Indian Community officials with a tool to efficiently manage emergency flood operations and flood mitigation efforts.

Maps were developed by using the U.S. Army Corps of Engineers' HEC–RAS and HEC–GeoRAS programs to compute water-surface profiles and to delineate estimated inundation areas for selected stream stages. Maps show estimated (shaded) inundation areas overlaid on high-resolution, georeferenced aerial photographs of the study area for stream stages between 37.00 and 41.00 feet at the USGS streamgage 05344500. The maps show the depth of water surrounding Prairie Island at stages 37.00, 39.00, 40.00 and 41.00 feet and provide users a general indication of depth of water at any point.

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