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Floods of June 2012 in Northeastern Minnesota

Scientific Investigations Report 2012–5283

U.S. Department of the Interior
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Cover. Left: View of homes flooded by the St. Louis River in the Fond du Lac neighborhood of Duluth, Minnesota, taken from a helicopter on June 21, 2012 (photograph provided by Walter Leu, Minnesota Department of Transportation).
Top right: An inundation map showing approximate flood-peak extents and depths for June 2012 for the St. Louis River at the Fond du Lac neighborhood of Duluth, Minnesota (entire map is in appendix 2 of the report). Map prepared by Christiana Czuba, U.S. Geological Survey, November 2012. Map base from 2010 National Agricultural Imagery program (U.S. Department of Agriculture, 2010).

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By Christiana R. Czuba, James D. Fallon, and Erich W. Kessler

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U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
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Conversion Factors and Datums

Inch/Pound to SI

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)
inch per hour (in/h)	0.0254	meter per hour (m/h)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88) or the National Geodetic Vertical Datum of 1929 (NGVD 29).

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

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
CDT	Central Daylight Time
CSG	crest-stage gage
DEM	digital elevation model
FEMA	Federal Emergency Management Agency
GIS	geographic information system
GPS	global positioning system
LiDAR	light detection and ranging
MDNR	Minnesota Department of Natural Resources
MDPS	Minnesota Department of Public Safety
MHSEM	Minnesota Homeland Security and Emergency Management
MnDOT	Minnesota Department of Transportation
NAVD 88	North American Vertical Datum of 1988
NGVD 29	National Geodetic Vertical Datum of 1929
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
RTK–GPS	Real-Time Kinematic Global Positioning System
TIN	triangular irregular network
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WIE	weighting of independent estimates

Acknowledgments

The authors would like to thank the National Weather Service, Minnesota Homeland Security and Emergency Management, and other member agencies of the Silver Jackets Hazard Mitigation Team for their coordination and assistance during the flood event and the course of this study. The city of Duluth and the U.S. Army Corps of Engineers Detroit District and St. Paul District are acknowledged for the collection of high-water-mark data that are included in this report.

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Floods of June 2012 in Northeastern Minnesota

By Christiana R. Czuba, James D. Fallon, and Erich W. Kessler

Abstract

During June 19–20, 2012, heavy rainfall, as much as 10 inches locally reported, caused severe flooding across northeastern Minnesota. The floods were exacerbated by wet antecedent conditions from a relatively rainy spring, with May 2012 as one of the wettest Mays on record in Duluth. The June 19–20, 2012, rainfall event set new records in Duluth, including greatest 2-day precipitation with 7.25 inches of rain. The heavy rains fell on three major watersheds: the Mississippi Headwaters; the St. Croix, which drains to the Mississippi River; and Western Lake Superior, which includes the St. Louis River and other tributaries to Lake Superior. Widespread flash and river flooding that resulted from the heavy rainfall caused evacuations of residents, and damages to residences, businesses, and infrastructure. In all, nine counties in northeastern Minnesota were declared Federal disaster areas as a result of the flooding.

Peak-of-record streamflows were recorded at 13 U.S. Geological Survey streamgages as a result of the heavy rainfall. Flood-peak gage heights, peak streamflows, and annual exceedance probabilities were tabulated for 35 U.S. Geological Survey streamgages. Flood-peak streamflows in June 2012 had annual exceedance probabilities estimated to be less than 0.002 (0.2 percent; recurrence interval greater than 500 years) for five streamgages, and between 0.002 and 0.01 (1 percent; recurrence interval greater than 100 years) for four streamgages. High-water marks were identified and tabulated for the most severely affected communities of Barnum (Moose Horn River), Carlton (Otter Creek), Duluth Heights neighborhood of Duluth (Miller Creek), Fond du Lac neighborhood of Duluth (St. Louis River), Moose Lake (Moose Horn River and Moosehead Lake), and Thomson (Thomson Reservoir outflow near the St. Louis River). Flood-peak inundation maps and water-surface profiles were produced for these six severely affected communities. The inundation maps were constructed in a geographic information system by combining high-water-mark data with high-resolution digital elevation model data. The flood maps and profiles show the extent and depth of flooding through the communities and can be used for flood response and recovery efforts by local, county, State, and Federal agencies.

Introduction

Flood information is needed by Federal, State, and local agencies to make informed decisions in meeting mission requirements related to flood hazard mitigation, planning, and response. For example, the Federal Emergency Management Agency (FEMA), U.S. Army Corps of Engineers (USACE), the National Weather Service (NWS) of the National Atmospheric and Oceanic Administration (NOAA), Minnesota Department of Natural Resources (MDNR), Minnesota Department of Public Safety (MDPS) and its division of Homeland Security and Emergency Management (MHSEM) need timely information on the magnitudes and frequency of floods to help respond to flood damage, enhance emergency response management, protect infrastructure, provide recovery guidance from the National Flood Insurance Program and State regulatory programs, and plan for future flood events.

In Minnesota, many of the agencies that need post-flood information are members of a State Hazard Mitigation Team commonly referred to as Silver Jackets. State Silver Jackets chapters are sponsored by the USACE and in Minnesota include as charter members, but is not limited to, the following agencies: USACE, FEMA, MDNR, MHSEM, NWS, and U.S. Geological Survey (USGS).

Heavy rains on June 19–20, 2012, caused severe flooding in northeastern Minnesota and prompted the NWS to issue areal flood, flash-flood, and river flood warnings. The **flood peaks**[1] were exacerbated by a relatively rainy spring, including one of the wettest Mays on record (Minnesota Department of Natural Resources State Climatology Office, 2012a). During the flooding in June 2012, evacuations, water rescues, and road closures were common in communities affected by the flooding. Damages from flooding were extensive and included major transportation disruptions and damage to homes and businesses, dams and flood-control structures, and parks and recreation areas. Damage caused by the flooding resulted in a Presidential Disaster Declaration on July 6, 2012, for the nine counties in northeastern Minnesota affected by the June 19–20, 2012, flood events (Federal Emergency Management Agency, 2012; fig. 1). This disaster declaration also includes a separate storm event in central Minnesota on June 14, 2012, for six counties (Federal Emergency Management Agency, 2012;

[1] Terms in **bold type** are defined in the Glossary at the back of the report.

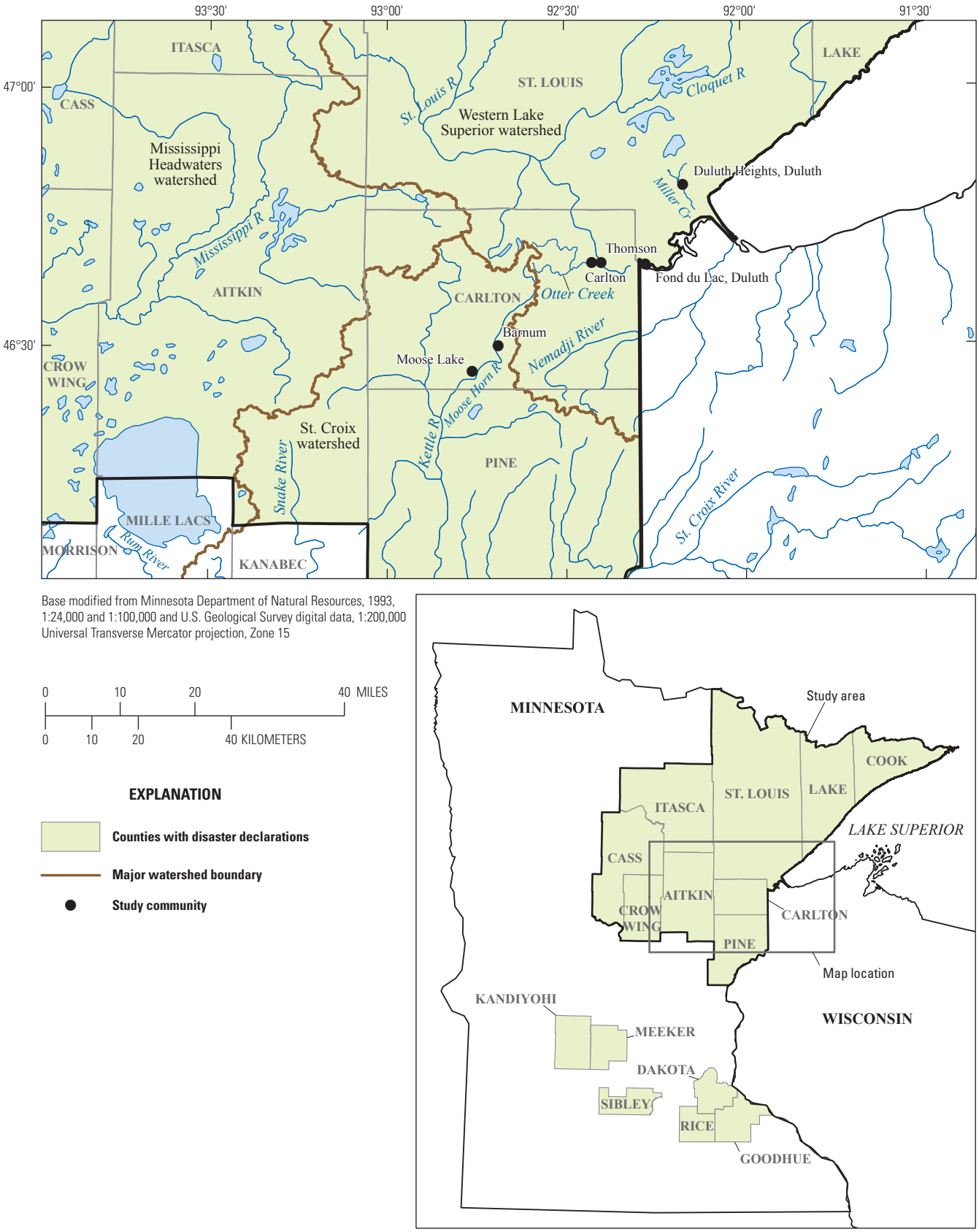

Figure 1. Locations of study communities in the counties with disaster declarations in northeastern Minnesota affected by the June 19–20, 2012, flood events.

Minnesota Department of Natural Resources State Climatology Office, 2012b); however, this report focuses only on the flooding effects in northeastern Minnesota, including the nine contiguous counties of Aitkin, Carlton, Cass, Cook, Crow Wing, Itasca, Lake, Pine, and St. Louis (fig. 1).

Given the severity of the June 2012 flooding in northeastern Minnesota, the USGS, in cooperation with FEMA, lead a study to document the meteorological and hydrologic conditions leading to the flood, and compile flood-peak **gage heights**, **streamflows**, and **annual exceedance probabilities** at USGS **streamgages**. The study also provided data to construct **flood profiles** and flood-peak inundation maps. Flood profiles and flood-peak inundation maps were constructed for six communities in northeastern Minnesota (fig. 1): Barnum (Moose Horn River), Carlton (Otter Creek), Duluth Heights neighborhood of Duluth (Miller Creek), Fond du Lac neighborhood of Duluth (St. Louis River), Moose Lake (Moose Horn River and Moosehead Lake), and Thomson (Thomson Reservoir outflow near the St. Louis River). The USGS and FEMA collaborated and consulted with Silver Jackets team members extensively in determining locations needing flood documentation.

Purpose and Scope

The purpose of this report is to document the floods of June 2012 in northeastern Minnesota. This report documents the magnitude and extent of flooding and the methods used to define the extent of flooding. **High-water-mark** data were collected after the flood and used to develop flood-peak inundation maps for the six communities most affected by the riverine flooding: Barnum (Moose Horn River), Carlton (Otter Creek), Duluth Heights neighborhood of Duluth (Miller Creek), Fond du Lac neighborhood of Duluth (St. Louis River), Moose Lake (Moose Horn River and Moosehead Lake), and Thomson (Thomson Reservoir outflow near the St. Louis River). The report summarizes meteorological and hydrologic conditions leading up to the flood. The severity of flooding is put into regional context by computing flood-peak magnitudes and annual exceedance probabilities at 35 USGS streamgages in the counties in northeastern Minnesota with disaster declarations. Flood effects and damages are summarized on the basis of information obtained from FEMA, NWS, MDPS, MHSEM, MDNR, Minnesota Department of Transportation (MnDOT), local agencies, news accounts, photographs, and corroborated testimony from individuals in flood-affected communities.

Conditions Leading to the 2012 Floods in Northeastern Minnesota

The June 2012 flooding in northeastern Minnesota was caused by heavy rainfall on areas that had already received above-normal precipitation. For much of northeastern Minnesota, spring and early summer had the highest total rainfall levels as compared to historical data for the same months (Minnesota Department of Natural Resources State Climatology Office, 2012c). May 2012 was one of the wettest Mays on record in some areas of central and northeastern Minnesota, and was the sixth wettest May on record for Duluth (Minnesota Department of Natural Resources State Climatology Office, 2012a).

In the weeks before the flooding rains of June 19–20, 2012, the ground was saturated from numerous storm systems that delivered 2–4 inches (in.) of rain across parts of northeastern Minnesota. On June 19, 2012, a **warm front** moved in and stalled across northern Minnesota, bringing waves of thunderstorms to the area (Graning and Hluchan, 2012). The heavy rainfall continued until late June 20, 2012, when a **cold front** moved through the area. Carlton County and southern St. Louis County had the highest levels of rainfall, and new records were set in Duluth, including greatest 2-day precipitation with 7.25 in. falling June 19–20, 2012 (Graning and Hluchan, 2012). Local reports of rainfall were as high as 8–10 in. throughout Duluth neighborhoods (Graning and Hluchan, 2012). This June 2012 flood event was the most damaging flood in Duluth's history, surpassing the August 1972 flood event (Minnesota Department of Natural Resources State Climatology Office, 2012d).

A spatial gridded dataset of estimated rainfall totals prepared by the NWS (National Weather Service, written commun., 2012) shows rainfall totals of 7 in. and greater for June 19–20, 2012, in parts of Carlton County and southern St. Louis County (fig. 2). Total rainfall amounts for six NWS Cooperative Observing—Fischer Porter precipitation stations in northeastern Minnesota recorded rainfall totals ranging from 2.73 in. at Eveleth in St. Louis County to 6.27 in. at Sandy Lake in Aitkin County for the storm event on June 19–20, 2012 (fig. 2; table 1). Local direct measurements of rainfall totals may differ from the spatial gridded dataset that is developed from radar data. A seventh Cooperative Observing—Fischer Porter precipitation station is located in Floodwood (not shown) in St. Louis County but was not included in this report because the gage was overtopped during the June rainfall and data were lost.

The cumulative 15-minute rainfall data from the six NWS Cooperative Observing—Fischer Porter precipitation stations (locations shown in fig. 2) indicate the magnitude and timing of the rain that fell throughout the storm events on June 19–20, 2012 (fig. 3). Instantaneous rainfall intensities were as great as 2 to 4 inches per hour (in/h) in the evening of June 19, 2012.

The heavy rains fell on three major watersheds: the Mississippi Headwaters; the St. Croix, which drains to the Mississippi River; and Western Lake Superior, which includes the St. Louis River and other tributaries to Lake Superior (fig. 2). Along the northern shore of Lake Superior, flash flooding was exacerbated by impervious soils and bedrock, and by the steep gradients of streams that drain directly to Lake Superior. In other areas receiving the heavy rainfall, storage from lakes and wetlands delayed and reduced the flood peaks but still resulted in record or near-record floods.

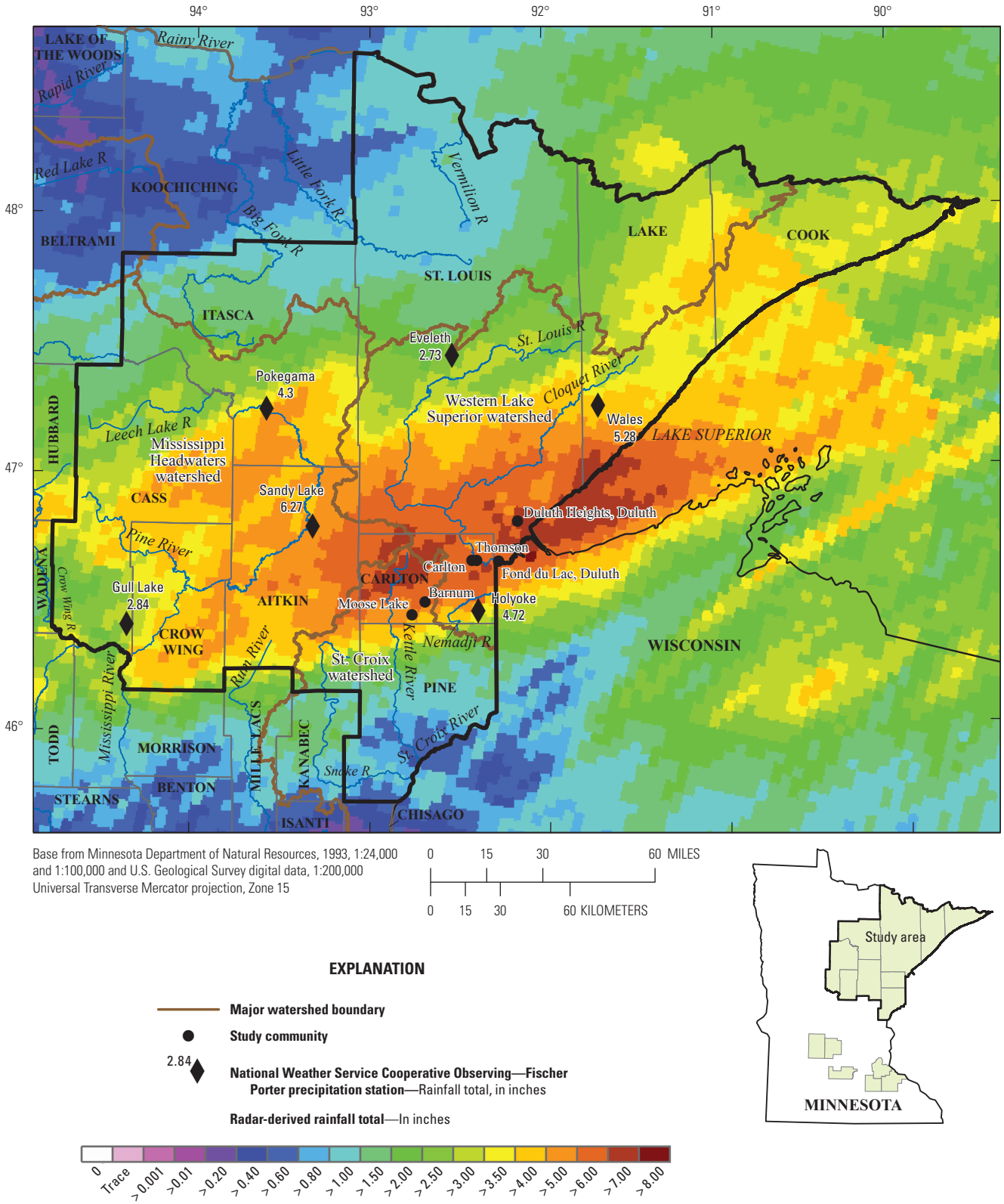

Figure 2. Distribution of 2-day rainfall totals for 7 a.m. Central Daylight Time June 19 through 7 a.m. Central Daylight Time June 21, 2012, and rainfall totals at selected National Weather Service (NWS) Cooperative Observing—Fischer Porter precipitation stations. Rainfall data provided by Steve Gohde and Diane Cooper of the National Weather Service (written commun., 2012).

Table 1. Provisional total rainfall for June 19–20, 2012, at selected National Weather Service (NWS) Cooperative Observing—Fischer Porter precipitation stations in northeastern Minnesota.

[Total rainfall from Steve Gohde and Diane Cooper of the National Weather Service (written commun., 2012). Annual exceedance probabilities from Huff and Angel (1992)]

Precipitation station name (location shown in fig. 2)	County	NWS station identifier	Total rainfall (inches)	48-hour duration rainfall (inches) for selected annual exceedance probabilities[1]				
				0.2	0.1	0.04	0.02	0.01
Eveleth	St. Louis	212645	2.73	3.21	3.74	4.49	5.06	5.63
Gull Lake	Cass	213411	2.84	3.38	3.97	4.86	5.62	6.45
Holyoke	Carlton	213863	4.72	3.53	4.03	4.74	5.36	6.02
Pokegama	Itasca	216612	4.30	3.38	3.97	4.86	5.62	6.45
Sandy Lake	Aitkin	217460	6.27	3.53	4.03	4.74	5.36	6.02
Wales	Lake	218613	5.28	3.21	3.74	4.49	5.06	5.63

[1]The annual exceedance probability is the probability that a given event will be exceeded or equaled in any given year. For example, the annual exceedance probability of the 100-year rainfall is 0.01. In other words, there is a 1-percent chance that the rainfall would be exceeded or equaled in any given year.

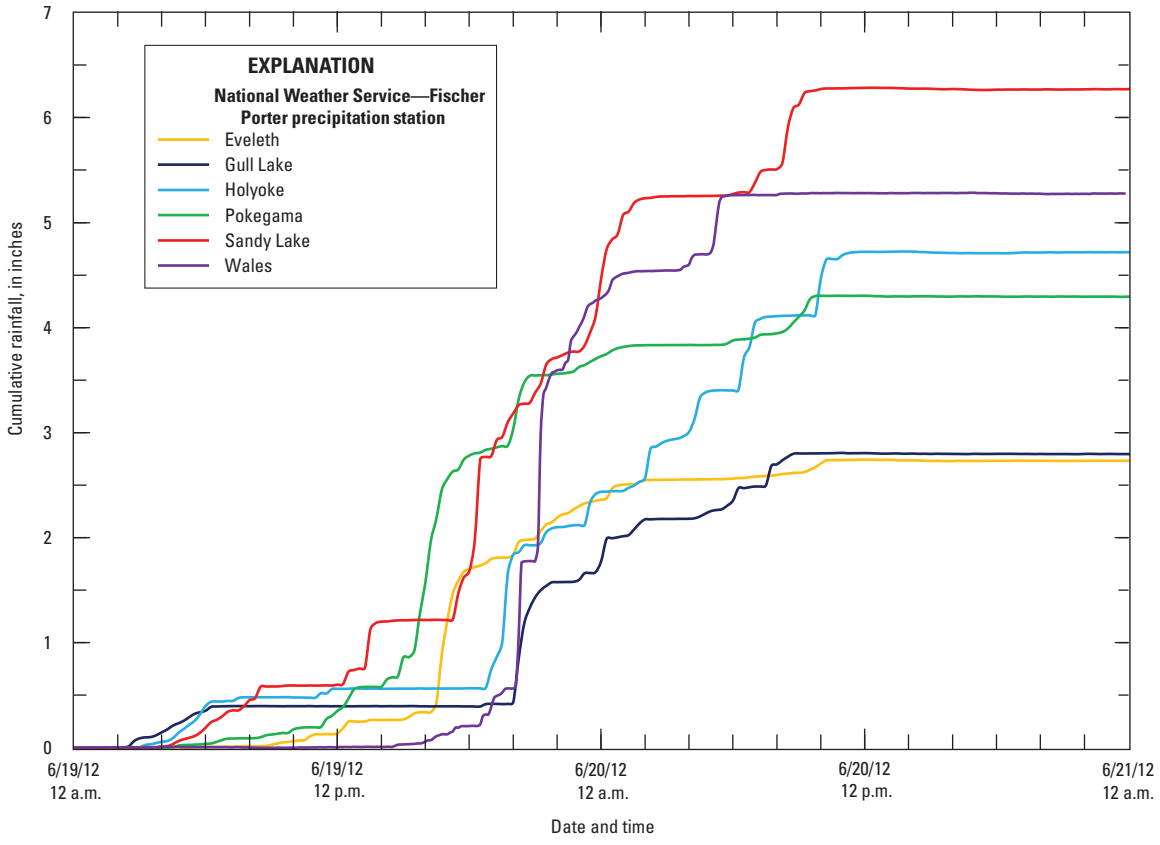

Figure 3. Cumulative daily rainfall during June 19–20, 2012, at selected National Weather Service (NWS) Cooperative Observing—Fischer Porter precipitation stations in northeastern Minnesota.

Methods

The methods used to compute magnitudes and annual exceedance probabilities of peak streamflows and to collect high-water-mark data are described in this section of the report. Methods used to create flood-peak inundation maps and water-surface profiles also are described.

Computing the Magnitudes of Peak Streamflows

Peak streamflows documented in this study were determined at 35 USGS streamgages (19 **continuous-record streamgages** and 16 **crest-stage gages**; locations shown in fig. 4). Continuous-record streamgages record stream levels continuously and for those referred to in this report, data are recorded electronically and telemetered to USGS offices for processing in near real time. Crest-stage gages (CSGs) are partial-record, nonmechanical, nontelemetered gages intended to record only the peak (crest) stream level since the last site visit.

For both types of streamgages, the peak streamflow is determined by an empirical relation developed between the stream level (also referred to as stage or gage height) and streamflow (also referred to as discharge) unique to each location. These stage-discharge relations at streamgages are developed and maintained by relating paired measurements of stage (gage height) and streamflow over the range of streamflows through time. Paired measurements used to develop a stage-discharge relation are determined most commonly by direct measurement of stage (observed/recorded) and streamflow (velocity meter) at the streamgages (Rantz and others, 1982); or, if direct measurement is not possible, by indirect hydraulic methods (Benson and Dalrymple, 1967). The stage-discharge relation is developed using available stage/discharge measurements and controlling hydraulic features of the channel. Stage-discharge relations can be extrapolated slightly beyond the highest measurement of stage/streamflow, depending on available information about channel geometry and hydraulic conditions (Rantz and others, 1982).

Flood-peak gage heights were obtained either from electronic data recorders at continuous-record streamgages or from CSGs. At both types of streamgages, peak gage heights were confirmed by independent secondary streamgages or by nearby high-water marks left as the streams receded from flood peak. At a few streamgages that were inundated by flood waters, peak gage heights were determined from surveyed high-water marks near streamgages. The stage-discharge relation at each streamgage was used to compute peak streamflow from the flood-peak gage height. Direct or indirect streamflow measurements served as flood-event data points for stage-discharge relation verification and extrapolation.

Estimating Annual Exceedance Probabilities of Peak Streamflows

The annual exceedance probability (AEP) for a particular streamflow is the probability of that streamflow being equaled or exceeded in any given year. An AEP of 0.01 has a 1 in 100 chance or 1-percent risk of being equaled or exceeded in any given year (Holmes and Dinicola, 2010). The AEP is related to the traditional concept of **recurrence interval**; by definition, the recurrence interval corresponding to a particular AEP is equal to 1 divided by the AEP (American Society of Civil Engineers, 1953; Holmes and Dinicola, 2010).

Streamflows for selected AEPs (0.10, 0.04, 0.02, 0.01, and 0.002) were estimated by using one of four methods: (1) the Bulletin 17B procedure presented by the Interagency Advisory Committee on Water Data (1982), (2) regional regression equations for rural conditions developed by Lorenz and others (2010), (3) the Expected Moments Algorithm (Cohn and others, 1997), or (4) weighting of independent estimates (WIE) procedure (Cohn and others, 2012; Interagency Advisory Committee on Water Data, 1982). Users of the Bulletin 17B procedure and regional regression equations for rural conditions calculate flood probabilities by fitting systematic annual peak-streamflow data to a log-Pearson type III (LPIII) distribution. The Expected Moments Algorithm is a generalization of the procedures in Bulletin 17B and was designed to better accommodate historical peak-flow data (known peak flows outside the period of continuous streamflow data collection) and left-censored data (peak flows less than what can be measured at the streamgage). The WIE method is used to reduce uncertainty in the AEP by combining the at-site estimate with the regional regression estimate from Lorenz and others (2010) for records at sites that are unregulated, unaffected by urbanization, and have a drainage area less than 3,000 square miles (mi^2) (Lorenz and others, 2010; Cohn and others, 2012). The June 2012 peak streamflows can then be related to the AEPs for each streamgage, by bracketing the observed streamflow with the streamflow magnitudes associated with the selected AEPs.

Collection of High-Water-Mark Data

High-water marks record the observed elevation of the flood peak, and provide the data needed to estimate the maximum flood-inundation surface. High-water marks were identified and flagged to document inundation levels in selected communities most affected by flooding, in addition to the high-water marks described previously that were collected at streamgages to confirm peak discharges. These high-water marks were collected by staff from the USGS, USACE, and city of Duluth in northeastern Minnesota during June and July 2012 after floodwaters had receded. To ensure consistent methods were used to identify and document high-water marks, USGS staff met with and provided other agency staff with documentation of the methods used.

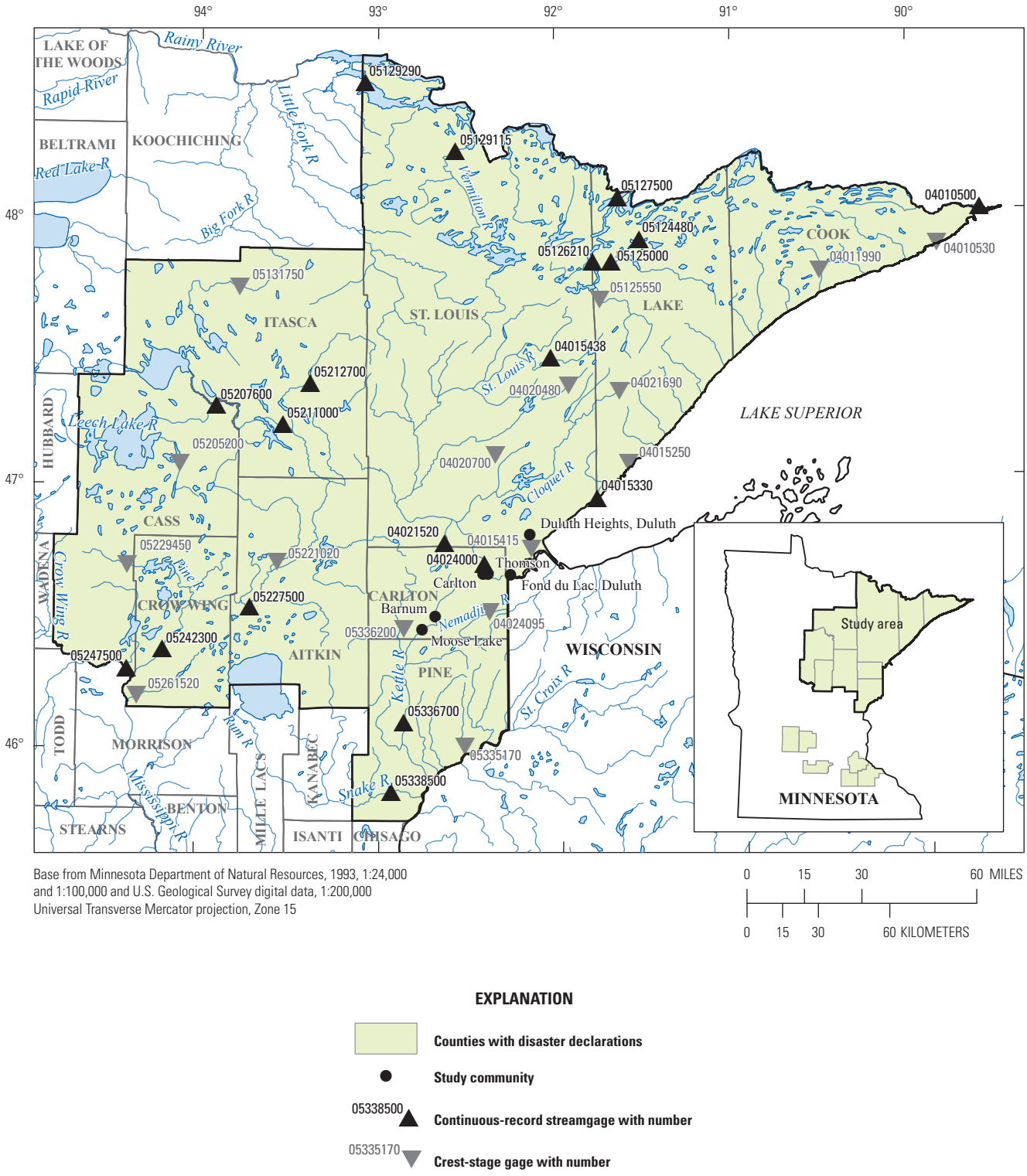

Figure 4. Locations of selected U.S. Geological Survey streamgages in the counties with disaster declarations for the floods of June 2012 in northeastern Minnesota.

Common high-water marks included stain lines and debris buildup on buildings, trees, or other structures that identify the highest level reached by the flooding waters. The quality of the high-water marks was subjectively rated in the field as excellent, good, fair, or poor by the high-water-mark crews. Ratings were based on the clarity of the mark and visual or hand-level comparison to nearby marks.

The high-water marks collected by the USGS were surveyed using Real-Time Kinematic Global Positioning System (RTK-GPS). The survey used a network of continuously operating global positioning system (GPS) stations, known as the MnDOT CORS Network (*http://www.dot.state.mn.us/surveying/CORS/CORS.html*), that provides real-time correction to the rover GPS through a cellular data connection, thus eliminating the need for a base station setup. Each survey was calibrated to a nearby MnDOT benchmark. Benchmarks were chosen based on the vertical accuracy rating of order 2 or better, as the vertical position of the high-water-mark data was deemed most critical. In the case of Carlton, Thomson, and Moose Lake, the horizontal order of the nearby usable benchmarks were not established. The horizontal position of the RTK-GPS survey was then adjusted using a noncalibrated GPS measurement at the benchmark or visual correction from aerial imagery.

The preferred method of surveying was to set the RTK-GPS rover up directly above the high-water mark. However, in many cases tree cover or building interference did not allow direct surveying of the high-water mark, and then a survey point was made a short distance away by transferring the elevation of the desired high-water mark to the survey point by using a hand level or string level. No correction for horizontal position was made. All USGS high-water marks were surveyed to an estimated vertical accuracy of 0.1 foot (ft), whereas the horizontal position may vary by as much as 15 ft.

The city of Duluth and the USACE Detroit District collected and surveyed high-water marks along Keene Creek (not shown), Kingsbury Creek (not shown), and Miller Creek, including in the Duluth Heights neighborhood of Duluth, using methods similar to the USGS collection and surveying methods. The USACE St. Paul District also provided high-water marks that are routinely collected during flood events, primarily at bridge structures and along roads, along selected rivers in the Mississippi and Kettle River Basins. The methods and accuracy of these data were not determined in this study. All high-water-mark data are included in appendix 1; table 1–1 contains the high-water marks for mapped communities of Barnum (Moose Horn River), Carlton (Otter Creek), Duluth Heights neighborhood of Duluth (Miller Creek), Fond du Lac neighborhood of Duluth (St. Louis River), Moose Lake (Moose Horn River and Moosehead Lake), and Thomson (Thomson Reservoir outflow near the St. Louis River), and table 1–2 contains the high-water marks for additional areas in northeastern Minnesota.

Flood-Peak Inundation Maps

Flood-peak inundation maps were produced from the high-water marks to show the extent and depth of the peak flooding. These maps were produced by use of geographic information system (GIS) software and associated programs (Morlock and others, 2008; Fitzpatrick and others, 2008; Fowler and others, 2010; Ellison and others, 2011), and a detailed description of the GIS process is described by Mastin and others (2010). The GIS layers of high-water-mark locations and elevations were used in conjunction with LiDAR-based 1-meter land-surface elevation data files. LiDAR, an acronym for "light detection and ranging," is remote sensing technology that is based on discrete light pulses and measured traveltimes. It is used to generate highly accurate three-dimensional representations of the Earth's surface, termed "digital elevation models" (DEMs) (National Oceanic and Atmospheric Administration, 2008). These DEMs were used to develop the inundation maps, which then were superimposed on the corresponding National Agricultural Imagery Program aerial imagery (U.S. Department of Agriculture, 2010). Note that LiDAR topography represents "bare earth" elevations, such that houses in the flood plain and bridge decks over the river centerline are removed. Additionally, LiDAR measurements do not penetrate water, so the elevation in water bodies approximately represents the water surface at the time of the LiDAR collection flights.

Water-surface elevation was assigned to the stream centerline based on nearby high-water-mark data with a linear interpolation along the stream centerline between adjacent high-water marks. However, the actual water surface may have had a different profile than the linear interpolation, hence the inundation may have been somewhat different than the mapped results. This is especially true at structures where no high-water-mark data were available; there may have been a sharper drop in the water-surface profile from the upstream to downstream side of a culvert or bridge structure. Cross-section lines were drawn across the valley representing a line of equal, potential peak water-surface elevation and, generally, were perpendicular to the direction of flow. A potential water-surface elevation was assigned to each cross section based on the water-surface elevation of the stream where they intersect. A triangular irregular network (TIN) was produced from the cross-section lines to produce a three-dimensional potential water surface. The terrain elevation (DEM) was subtracted from the potential water-surface elevation TIN, resulting in a GIS coverage where positive values represent the depth of inundation.

Flood-Peak Water-Surface Profiles

Standard USGS methods were used to develop flood-peak water-surface profiles from the high-water-mark elevations and locations (Benson and Dalrymple, 1967; Lumia and others, 1986). Flood profiles were produced for the mapped

stream reaches for the six severely affected communities in northeastern Minnesota by plotting high-water-mark elevations by mile of stream as measured upstream on the centerline of the **thalweg** from the downstream boundary of each study reach. Because the flood-inundation in Thomson represented flow across the landscape, the profile was measured along an approximate centerline of the flow rather than along the nearby stream thalweg. The water surface between high-water marks was estimated by linear interpolation. A linear interpolation between high-water marks is an approximation of the actual water surface.

Floods of June 2012 in Northeastern Minnesota

The estimated AEPs of peak streamflows for the floods of June 2012 are presented in this section of the report. Flood-peak inundation maps and flood-peak water-surface profiles also are presented.

Magnitudes and Estimated Annual Exceedance Probabilities of Peak Streamflows

The magnitudes (flood-peak gage-height data and peak-streamflow data) and estimated AEPs from the June 2012 floods are presented for 34 of the 35 streamgages (table 2). The Mississippi River at Willow Beach at Ball Club (streamgage 05207600) does not have sufficient historical record to compute AEPs, and the basin characteristics are beyond the range applicable by the regression equations. New peak-of-record streamflows were recorded at 13 USGS streamgages as a result of the heavy rainfall, including the St. Louis River at Scanlon (streamgage 04024000), which has more than 100 years of streamflow records. Flood-peak streamflows in June 2012 had AEPs estimated to be less than 0.002 (0.2 percent; recurrence interval greater than 500 years) for five streamgages, and between 0.002 and 0.01 (1 percent; recurrence interval greater than 100 years) for four streamgages (table 2).

The timing of peak flows for streams of differing size is evident in the plot of the stage hydrographs for selected streamgages for the flood event (fig. 5). Streams and smaller rivers were quick to respond to the intense rainfall, such as the Knife River near Two Harbors (04015330), which peaked at an estimated 25,000 cubic feet per second (ft^3/s) on June 20, 2012, exceeding the previous peak of record of 7,440 ft^3/s from May 1979 (table 2). Some larger rivers also had rapid rises in streamflow in response to the intense rainfalls late on June 19, 2012, such as the St. Louis River at Scanlon (04024000), which peaked at 45,300 ft^3/s on June 21, 2012 (table 2). Other large rivers, such as the Mississippi River, had a more delayed response time as the water accumulated from tributaries; the peaks also were affected by dam and reservoir management activities (fig. 5).

Flood-Peak Inundation Maps and Water-Surface Profiles

Flood-peak inundation maps (figs. 2–1 to 2–6 in appendix 2) and flood-peak water-surface profiles (figs. 3–1 to 3–6 in appendix 3) were produced for the six communities of Barnum (Moose Horn River), Carlton (Otter Creek), Duluth Heights neighborhood of Duluth (Miller Creek), Fond du Lac neighborhood of Duluth (St. Louis River), Moose Lake (Moose Horn River and Moosehead Lake), and Thomson (Thomson Reservoir outflow near the St. Louis River), respectively. Personnel from the USGS, USACE Detroit District, and city of Duluth flagged and surveyed high-water marks in June and July 2012 in these six most severely affected communities. The city of Duluth and the USACE Detroit District also surveyed high-water marks along Keene Creek (not shown), Kingsbury Creek (not shown), and the lower part of Miller Creek. The USACE St. Paul District collected high-water marks at bridge structures along the Mississippi River and Diversion Channel in the Mississippi River Basin, and along the Moose Horn, Kettle, Pine, and Willow Rivers in the Kettle River Basin. Descriptions of all the high-water marks are listed in appendix 1; only the locations of high-water marks in the six mapped communities are shown in the report figures.

A flood-peak inundation map was generated for each community showing the maximum extent and depth of flood-waters in and around the community (appendix 2). Inundation maps contain locations and elevations of the high-water marks, along with an indication of whether each high-water mark was used to develop the flood-peak water-surface. If a data point was substantially higher or lower when compared to neighboring points, the point in question was not used in interpolating the water surface for the inundation map. For example, high-water marks MOOSE1 and MOOSE2 (table 1–1) in the community of Moose Lake were substantially lower than other high-water marks in the area and were not used to interpolate the water surface for mapping the flood inundation (figs. 2–5 and 3–5). It is assumed that these marks were left as flood waters receded and were not representative of the peak water surface. In the Fond du Lac neighborhood of Duluth, numerous high-water marks were collected in proximity to each other; however, the elevations do not agree in connecting a single peak water-surface profile along the St. Louis River (figs. 2–4 and 3–4). The elevations from high-water-mark identifiers FDL1, FDL3, and FDL10 were used in the flood-inundation mapping for the upstream part of the profile, whereas the other nearby high-water marks that are all lower in elevation and likely not representative of the peak water surface were disregarded. Additionally, high-water-mark identifier FDL9 was on a hill with substantial flow heading downslope towards the St. Louis River, and was not used for the water-surface profile along the St. Louis River.

Table 2. Provisional flood-peak gage heights, peak streamflows, and annual exceedance probabilities of peak streamflows during the floods of June 2012 at selected U.S. Geological Survey streamgages in northeastern Minnesota.

[mi^2, square miles; ft, feet; NGVD 29, National Geodetic Vertical Datum of 1929; WY, water year; ft^3/s, cubic feet per second; %, percent; Minn., Minnesota; e, estimated, >, greater than; <, less than; --, data not available]

Station number	Stream and community	Drainage area (mi^2)	Gage vertical datum (ft above NGVD 29)	Water years[1] with peak-flow records	Length of record of annual peaks (years)	Peak flow for period of record prior to WY 2012			Peak flow for June 19–30, 2012 floods			Annual exceedance probability[2] for June 2012 peak streamflow	Estimated streamflow of 0.01 (1%) annual exceedence probability
						Date	Gage height (ft above gage datum)	Stream-flow (ft^3/s)	Date	Gage height (ft above gage datum)	Stream-flow (ft^3/s)		
04010500	Pigeon River at Middle Falls near Grand Portage, Minn.	609	787.58	1924–2011	88	5/5/1934	7.60	11,000	6/20/2012	8.76	3,700	> 0.10	[3]11,700
[4]04010530	Reservation River near Hovland, Minn.	16.5	660.00	1991–92, 2000–11	14	7/31/2009	3.68	> 1,350	6/20/2012	4.05	1,300	0.10–0.04	[5]2,130
[4]04011990	Cascade River at Forest Road 45 near Grand Marais, Minn.	87.6	1,500.00	1985–2011	27	4/24/2001	13.36	1,810	6/20/2012	11.38	[6]671	> 0.10	[5]2,590
[4]04015250	Silver Creek tributary near Two Harbors, Minn.	3.62	Undetermined[7]	1965–2011	47	9/20/1972	17.08	1,880	6/20/2012	17.50	[8]2,200	0.01–0.002	[5]1,890
04015330	Knife River near Two Harbors, Minn.	83.6	Undetermined[7]	1975–2011	37	5/10/1979	11.16	7,440	6/20/2012	12.81	[8,9]25,000	< 0.002	[5]9,920
[4]04015415	Lake Superior tributary at West 9th Street in Duluth, Minn.	1.81	Undetermined[7]	2001–11	11	8/2/2010	9.72	175	6/20/2012	11.61	[8]740	< 0.002	[10]226
[11]04015438	St. Louis River near Skibo, Minn.	101	1,500.00	--	--	--	--	--	6/24/2012	20.79	[8]813	> 0.10	[12]1,800
[4]04020480	North Branch Whiteface River near Fairbanks, Minn.	17.1	Undetermined[7]	1979–2011	33	4/23/1979	13.67	660	6/21/2012	13.90	649	0.02–0.01	[5]700
[4]04020700	Bug Creek at Shaw, Minn.	24.8	Undetermined[7]	1979–2011	33	7/5/1999	18.00	[9]1,350	6/21/2012	18.10	[8]1,580	0.01–0.002	[5]1,380
04021520	Stoney Brook at Pine Drive near Brookston, Minn.	74.0	Undetermined[7]	2005–11	7	4/27/2008	7.70	453	6/21/2012	12.34	[8]1,170	0.02–0.01	[12]1,290
[4]04021690	Cloquet River near Toimi, Minn.	40.8	1,700.00	1986–2011	26	7/4/1993	9.06	1,540	6/21/2012	8.30	1,110	0.04–0.02	[5]1,460
04024000	St. Louis River at Scanlon, Minn.	3,430	1,101.23	1908–2011	104	5/9/1950	--	[13]37,900	6/21/2012	16.62	[8]45,300	< 0.002	[3]38,400
[4]04024095	Nemadji River near Holyoke, Minn.	127	756.12	1972–2011	40	8/3/2011	18.60	5,300	6/20/2012	21.05	[8,9]9,700	< 0.002	[5]5,830
05124480	Kawishiwi River near Ely, Minn.	254	Undetermined[7]	1967–2011	45	5/4/2001	6.07	1,870	6/24/2012	4.91	793	> 0.10	[5]2,540
05125000	South Kawishiwi River near Ely, Minn.	--	1,430.00	1952–61, 1976–78, 2003–11	22	4/21/1976	7.18	4,980	6/26/2012	5.69	2,560	> 0.10	[10]8,000
[4]05125550	Stony River near Babbitt, Minn.	215	Undetermined[7]	1976–80, 1986–2011	31	4/19/1976	8.71	2,490	6/26/2012	7.31	1,480	> 0.10	[5]3,090
05126210	South Kawishiwi River above White Iron Lake near Ely, Minn.	837	Undetermined[7]	1976–78, 2003–11	12	4/22/1976	11.42	8,080	6/26/2012	9.49	4,890	> 0.10	[3]12,700
05127500	Basswood River near Winton, Minn.	1,740	1,296.80	1926–27, 1930–2011	84	5/24/1950	6.94	[13]15,600	6/30/2012	5.59	4,370	> 0.10	[3]12,400
05129115	Vermilion River near Crane Lake, Minn.	905	1,180.00	1979–2011	33	4/1979	15.15	4,600	6/21/2012	10.20	[6]1,520	> 0.10	[5]5,660
05129290	Gold Portage outlet from Kabetogama Lake near Ray, Minn.	--	Undetermined[7]	1983–94, 1998–2011	26	5/29/2001	([14])	1,310	6/21/2012	18.38	[6]770	> 0.10	[3]1,320
[4]05131750	Big Fork River near Bigfork, Minn.	606	Undetermined[7]	1973–2011	38	4/22/1979	15.48	2,830	6/21/2012	< 10.59	[6]< 783	> 0.10	[5]3,150
[4]05205200	Boy River near Remer, Minn.	289	Undetermined[7]	1986–2011	26	7/23/1987	11.64	660	6/22/2012	11.14	420	> 0.10	[5]1,040
05207600	Mississippi River at Willow Beach at Ball Club, Minn.	2,850	Undetermined[7]	2008–11	4	2/18/2011	[14, 15]11.50	[13]2,720	6/24/2012	8.71	[6]1,410	Undetemined[16]	Undetemined[16]
05211000	Mississippi River at Grand Rapids, Minn.	3,370	1,242.03	1942–2011	70	9/3/1948	15.20	[13]12,500	6/19/2012	8.41	[6]3,190	> 0.10	[10]4,740
05212700	Prairie River near Taconite, Minn.	371	1,294.81	1968–83, 2001–11	27	4/17/1969	11.81	3,260	6/27/2012	7.91	[6]942	> 0.10	[5]4,860

Table 2. Provisional flood-peak gage heights, peak streamflows, and annual exceedance probabilities of peak streamflows during the floods of June 2012 at selected U.S. Geological Survey streamgages in northeastern Minnesota.—Continued

[mi², square miles; ft, feet; NGVD 29, National Geodetic Vertical Datum of 1929; WY, water year; ft³/s, cubic feet per second; %, percent; Minn., Minnesota; e, estimated, >, greater than; <, less than; --, data not available]

Station number	Stream and community	Drainage area (mi²)	Gage vertical datum (ft above NGVD 29)	Water years[1] with peak-flow records	Length of record of annual peaks (years)	Peak flow for period of record prior to WY 2012			Peak flow for June 19–30, 2012 floods			Annual exceedance probability[2] for June 2012 peak streamflow	Estimated streamflow of 0.01 (1%) annual exceedence probability
						Date	Gage height (ft above gage datum)	Stream-flow (ft³/s)	Date	Gage height (ft above gage datum)	Stream-flow (ft³/s)		
[4]05221020	Willow River below Palisade, Minn.	523	Undetermined[7]	1972–2011	40	4/25/1979	17.25	3,730	6/28/2012	17.43	3,440	0.10–0.04	[5]4,820
05227500	Mississippi River at Aitkin, Minn.	6,140	1,182.41	1888–99, 1902–2011	112	5/20/1950	22.49	[13]20,000	6/28/2012	18.71	15,100	0.04–0.02	[3]16,400
[4]05229450	Pine River near Pine River, Minn.	261	1,279.00	1986–2011	26	5/14/1999	5.15	1,520	6/23/2012	5.74	[8,9]2,000	0.01–0.002	[5]1,900
05242300	Mississippi River at Brainerd, Minn.	7,320	1,146.96	1988–2011	24	4/30/2001	16.70	[13]17,500	6/28/2012	17.61	[8]17,900	0.02–0.01	[10]19,100
05247500	Crow Wing River near Pillager, Minn.	3,760	1,151.00	1965, 1969, 1970–2011	43	4/14/1965		[13]18,300	6/24/2012	7.35	[6]6,860	> 0.10	[3]20,600
[4]05261520	Nokasippi River near Fort Ripley, Minn.	193	Undetermined[7]	1986–2011	26	6/26/2003	15.17	1,160	6/22/2012	15.10	[8]1,200	0.10–0.04	[5]1,740
[4]05335170	Crooked Creek near Hinckley, Minn.	94.4	Undetermined[7]	1986–2011	26	4/23/2001	16.65	2,100	6/22/2012	15.02	[6]1,380	> 0.10	[5]2,790
[4]05336200	Glaisby Brook near Kettle River, Minn.	27.0	1,105.00	1960–2011	52	7/22/1972	10.18	1,370	6/20/2012	12.26	[8,9]> 2,000	0.01–0.002	[5]1,520
05336700	Kettle River below Sandstone, Minn.	868	931.50	1965, 1968–2011	45	7/23/1972	15.38	17,200	6/22/2012	18.22	[8]24,800	< 0.002	[5]17,900
05338500	Snake River near Pine City, Minn.	974	Undetermined[7]	1914–17, 1950, 1952–2011	61	7/27/1972	10.38	14,300	6/26/2012	5.66	[6]2,930	> 0.10	[5]15,300

[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]The annual exceedance probability is the probability that a given event magnitude will be equaled or exceeded in any given year and is the reciprocal of the recurrence interval. The recurrence interval is the average interval of time within which the given flood will be equaled or exceeded once (American Society of Civil 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%); and for 100 years, 0.01 (1%).

[3]Streamflow computed from Expected Moments Algorithm (Cohn and others, 1997).

[4]U.S. Geological Survey crest-stage or peak-stage gage.

[5]Streamflow from weighting of independent estimates (WIE) procedure (Interagency Advisory Committee on Water Data, 1982, appendix 8). The independent estimates were based on Lorenz and others (2010).

[6]June 2012 peak was not peak of water year 2012.

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

[8]New streamflow peak of record.

[9]Streamflow is an estimate.

[10]Streamflow computed from Bulletin 17B, Guidelines for Determining Flood Flow Frequency (Interagency Advisory Committee on Water Data, 1982).

[11]Streamgage was installed August 2011.

[12]Streamflow from Lorenz and others (2010) regression equations.

[13]Streamflow affected to unknown degree by regulation or diversion.

[14]Gage height not the maximum for the year.

[15]Gage height affected by backwater.

[16]Recurrence-interval flows have not been established. One or more basin characteristics are beyond the range used for development of models from regression analysis.

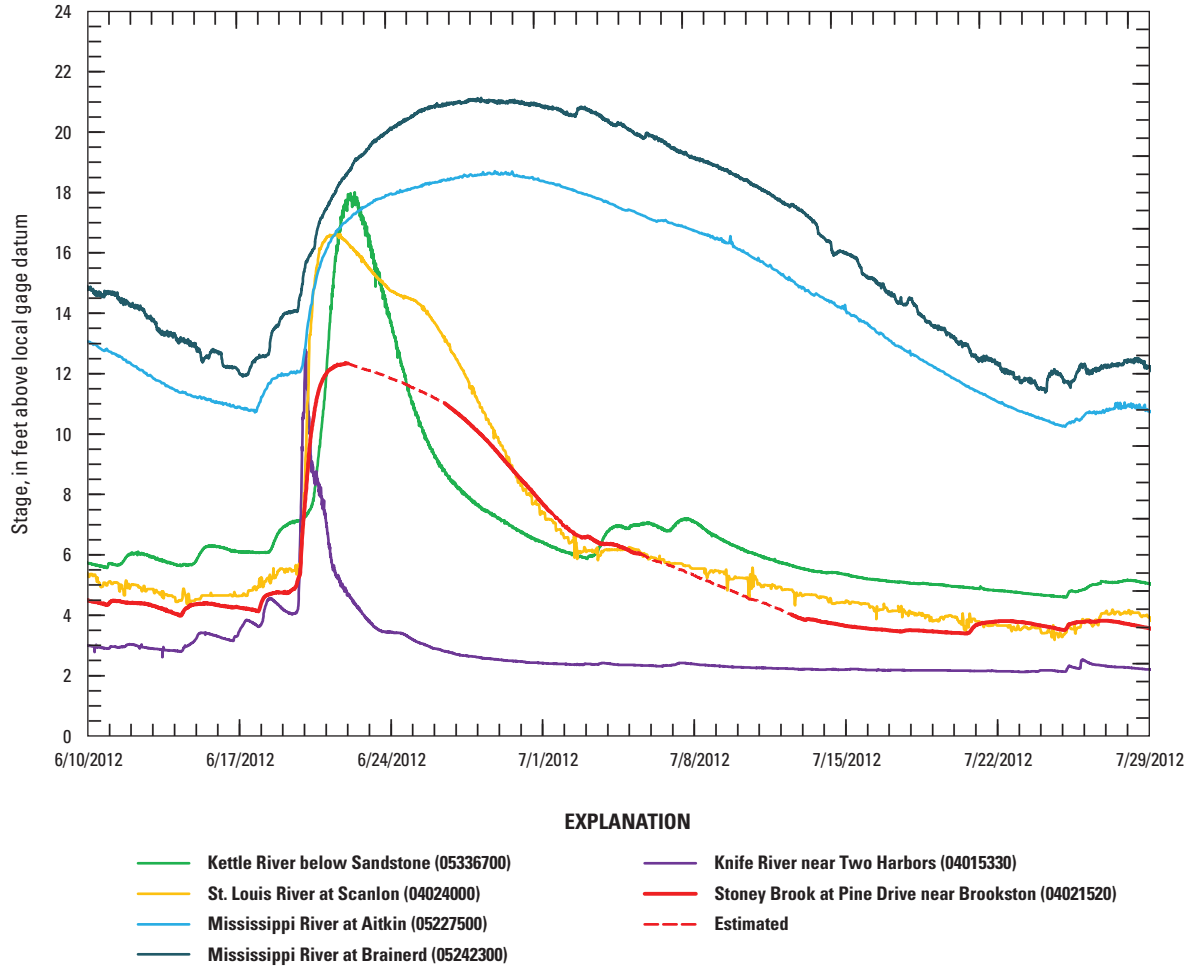

Figure 5. Provisional stage hydrographs at selected U.S. Geological Survey streamgages in northeastern Minnesota for June 10 through July 29, 2012.

The maps were checked by USGS surveying and high-water-mark personnel, and the high-water marks were compared spatially to check for mathematical or other errors. Anecdotal information from local residents was used to interpret the water-surface profile between high-water marks and to extrapolate the area of inundation beyond the surveyed area as necessary. The maps also were visually compared to photographs and videos of flooding available online and from local residents, as well as aerial photographs taken by MnDOT personnel from a helicopter during the flooding. Not all photographs and videos were taken during peak flooding and they are indicative of the minimum area that was flooded. Aerial photographs were used to extrapolate the maps beyond the extent of surveyed high-water marks; for example, the inundation in Fond du Lac neighborhood of Duluth extended downstream and to the north away from the river corridor where most high-water marks were found and surveyed. The elevation and extent of the flood waters were inferred from the MnDOT aerial photographs at easily identifiable edges of water across the roadways.

Flood-peak water-surface profiles were produced from the high-water-mark data along the thalweg (appendix 3). The profiles include only the high-water marks that were used to determine the elevation of the flood-peak water-surface (appendix 2). The only exception is that the water-surface profile for Thomson does not include high-water-marks ETHOM1 and ETHOM2, which were used to map the water-surface elevation of the east side of town but are not adjacent to the primary flow path that is represented in the water-surface profile (figs. 2–6 and 3–6). Flood-peak profiles show how the flood-peak inundation surface and slope varied along the stream reach through each of the six communities. Locations of bridge crossings were added to the profiles to provide additional context.

Although few high-water marks were identified in Barnum (fig. 2–1), photographs taken by residents during the floods also provided information on what areas of town were flooded by the Moose Horn River. Southwest of town, inundation was mapped by assuming that floodwaters spilled out of the channel and backed up this drainage area that normally flows north into the Moose Horn River during low-flow conditions.

The city of Carlton also is located near Thomson Reservoir; however, flooding in Carlton originated from Otter Creek

on the south side of town. Otter Creek flows east until it joins the St. Louis River downstream of Thomson Reservoir. As the floodwaters in Otter Creek rose, they spilled northward across the train tracks and flowed through town along two pathways (fig. 2–2). The floodwaters likely flowed north of town, then turned and flowed east along a drainage path south of Thomson Reservoir.

The flooding in the Duluth Heights neighborhood in Duluth was from Miller Creek, and affected businesses along Miller Trunk Highway (fig. 2–3). Parts of Miller Trunk Highway were inundated and the road was temporarily closed.

Also in Duluth, the Fond du Lac neighborhood was substantially inundated by the St. Louis River (fig. 2–4). Floodwaters inundated most residences along the north side of the river. Highway 23 was underwater in several locations and was closed to traffic.

The town of Moose Lake was flooded along Moosehead Lake on the Moose Horn River (fig. 2–5). Much of the rain that contributed to flooding in Moose Lake fell on the contributing watershed farther upstream. The Moose Horn River enters the northeast corner of Moosehead Lake, and exits in its southwest corner. The Portage River also is tributary to Moosehead Lake, entering at the east side. The water surface of the lake was mapped at an elevation of 1,052.5 ft for the entire area of the expanded lake. Floodwaters inundated houses, schools, and a campground.

The St. Louis River exits Thomson Reservoir (fig. 2–6) at the dam west of the town of Thompson. Although the flooding along the St. Louis River washed out part of the Highway 210 roadway, this area was not in the study area for inundation mapping. Floodwaters spilled out of Thomson Reservoir at several small dam structures and flowed overland into the town of Thomson. The more destructive floodwaters flowed overland and south along Vermillion Street, flooding houses and causing substantial damage to the street. This water continued to flow southeast across Highway 210 and joined the St. Louis River south of the study limit (fig. 2–6). On the eastern side of Thomson, the floodwaters flowed down the forested hill from the reservoir and flooded houses along Dalles Avenue. Two culverts at the study boundary (indicated by the deeper inundation depths at the southern study boundary on fig. 2–6) could not pass all the flow to the south, which backed up water and caused it to flow west along Dalles Avenue and join with the floodwaters from Vermillion Street. Farther to the east, a diversion canal that conveys water from Thomson Reservoir downstream to Minnesota Power facilities also was beyond the study limit.

Description of Flood Damages and Effects

Heavy rainfall on already saturated land caused widespread flash flooding and river flooding in northeastern Minnesota in June 2012. Transportation disruptions were widespread, and road closures were common across Itasca, Aitkin, Carlton, southern Lake, and southern St. Louis Counties. Damages included residences, infrastructure, businesses, public parks, and recreation facilities. The most severely affected communities, and the focus of this study for inundation mapping, included Barnum (Moose Horn River), Carlton (Otter Creek), Duluth Heights neighborhood of Duluth (Miller Creek), Fond du Lac neighborhood of Duluth (St. Louis River), Moose Lake (Moose Horn River and Moosehead Lake), and Thomson (Thomson Reservoir outflow near the St. Louis River). Nearby communities such as Floodwood (not shown), Fond du Lac Indian Reservation (not shown), and Cloquet (not shown) also received extensive flooding and damage and were inspected by field crews but were beyond the scope of this study and not surveyed for high-water marks.

The floods in northeastern Minnesota caused more than an estimated $100 million dollars in damages. Following is a summary of damage assessment compiled after June 2012 primarily from news releases and information by the Minnesota Department of Public Safety, Homeland Security and Emergency Management (2012):

- Road closures included Interstate 35 through Duluth and south of Carlton, as well as numerous State highways and local roads.
- Evacuations included Barnum, Thomson, and part of Moose Lake (Carlton County), parts of Fond du Lac neighborhood of Duluth, and Willow River (not shown; Pine County).
- Evacuation sites were set up in Duluth, Carlton, Scanlon (not shown), and Askov (not shown).
- Red Cross staffed evacuation sites, and Salvation Army provided meals.
- Food and drinking-water distribution points were set up in the affected areas.
- The Lake Superior Zoo in Duluth experienced damage as Kingsbury Creek (not shown) flooded, including the loss of 14 animals and damage of structures. Several other animals were swept from their enclosures but were safely rescued (Lake Superior Zoo, 2012).
- Jay Cooke State Park (not shown) was closed due to severe damage to the entrance route on Highway 210. The park's iconic swinging bridge over the St. Louis River was severely damaged.
- Other parks (not shown on maps) were temporarily closed or had restricted access, including Savanna Portage State Park, Moose Lake State Park, Willard Munger State Trail, Cuyuna Country State Recreation Area, and Soo Line and Blind Lake ATV trails in Aitkin County.

Preliminary damage assessments were done in 13 counties and the Fond du Lac Indian Reservation in the days after the flood. Assessment teams included Federal officials from FEMA, State officials from MHSEM, and local officials. On July 6, 2012, President Obama declared a major disaster existed in northeastern and central Minnesota for the June 14–21, 2012, storm and flood events (Federal Emergency Management Agency, 2012). The disaster declaration brought much needed additional assistance for residents and businesses. This declaration made public assistance requested by the Governor available to State and eligible local governments, and certain private nonprofit organizations on a cost-sharing basis for emergency work and the repair or replacement of facilities damaged by the severe flooding in Aitkin, Carlton, Cass, Cook, Crow Wing, Dakota, Goodhue, Itasca, Kandiyohi, Lake, Meeker, Pine, Rice, St. Louis, and Sibley Counties, as well as the Fond du Lac (not shown), Grand Portage (not shown), and Mille Lacs (not shown) Indian Reservations. This declaration also made Hazard Mitigation Grant Program assistance requested by the Governor available for hazard-mitigation measures statewide.

Summary

During June 19–20, 2012, heavy rainfall, as much as 10 inches locally reported, caused severe flooding across northeastern Minnesota. The floods were exacerbated by wet antecedent conditions from a relatively rainy spring, with May 2012 as one of the wettest Mays on record in Duluth. The June 19–20, 2012, rainfall event set new records in Duluth, including greatest 2-day precipitation with 7.25 inches of rain. The heavy rains fell on three major watersheds: the Mississippi Headwaters; the St. Croix, which drains to the Mississippi River; and Western Lake Superior, which includes the St. Louis River and other tributaries to Lake Superior. Widespread flash and river flooding in northeastern Minnesota that resulted from the heavy rainfall caused more than $100 million dollars in damages. In all, nine counties in northeastern Minnesota were declared Federal disaster areas as a result of the flooding. The June 2012 flooding caused widespread transportation disruptions across Itasca, Aitkin, Carlton, southern Lake, and southern St. Louis Counties. Damages included residences, infrastructure, businesses, public parks, and recreation facilities.

Peak-of-record streamflows were recorded at 13 U.S. Geological Survey streamgages as a result of the heavy rainfall. Flood-peak gage heights, peak streamflows, and annual exceedance probabilities were tabulated for 35 U.S. Geological Survey streamgages. Flood-peak streamflows in June 2012 had annual exceedance probabilities estimated to be less than 0.002 (0.2 percent; recurrence interval greater than 500 years) for five streamgages, and between 0.002 and 0.01 (1 percent; recurrence interval greater than 100 years) for four streamgages. High-water marks were identified and tabulated for the most severely affected communities of Barnum (Moose Horn River), Carlton (Otter Creek), Duluth Heights neighborhood of Duluth (Miller Creek), Fond du Lac neighborhood of Duluth (St. Louis River), Moose Lake (Moose Horn River and Moosehead Lake), and Thomson (Thomson Reservoir outflow near the St. Louis River). Flood-peak inundation maps and water-surface profiles were produced for these six severely affected communities. The inundation maps were constructed in a geographic information system by combining high-water-mark data with high-resolution digital elevation model data. The flood maps and profiles show the extent and depth of flooding through the communities and can be used for flood response and recovery efforts by local, county, State, and Federal agencies.

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Glossary

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

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, there is a 1-percent chance that the 100-year peak flow will be exceeded or equaled in any given year. 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 one divided by the flood probability (Holmes and Dinicola, 2010).

cold front A zone separating two air masses, of which the cooler, denser mass is advancing and replacing the warmer mass (National Weather Service, 2009).

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, it 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 it is necessary to distinguish between specific types of instrumentation or data used at a streamgage, 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.

thalweg The area of maximum water velocity within a channel flow (Charlton, 2009).

warm front A transition zone between a mass of warm air and the colder air it is replacing (National Weather Service, 2009).

Appendix 1. High-Water-Mark Descriptions

Table 1–1. High-water-mark descriptions for the mapped communities of Barnum, Carlton, Duluth Heights neighborhood in Duluth, Fond du Lac neighborhood in Duluth, Moose Lake, and Thomson for the floods of June 2012 in northeastern Minnesota.

[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. Approximate quality ratings of high-water marks: Excellent, plus or minus (±) 0.02 foot; Good, ± 0.05 foot; Fair, ± 0.1 foot; and Poor, greater than 0.10 foot (Lumia and others, 1986).°, degrees; ′, minutes; ″, seconds; --, not available; USACE, U.S. Army Corps of Engineers; USGS, U.S. Geological Survey]

Elevation (feet above NAVD 88)	Latitude	Longitude	High-water-mark quality	High-water-mark description	High-water-mark identifier	Agency that collected data
				Barnum		
1,099.0	46°30′56.8″	92°41′55.6″	--	Debris line	MR8	USACE St. Paul District
1,097.3	46°30′12.8″	92°41′36.7″	Good	Mud line on building	BARN1	USGS
1,096.3	46°30′16.3″	92°41′32.5″	--	--	MR7	USACE St. Paul District
1,094.4	46°30′8.6″	92°41′29.2″	Poor	Debris line in tree	BARN2	USGS
1,094.0	46°30′8.2″	92°41′28.8″	--	--	MR6	USACE St. Paul District
1,094.0	46°30′4.8″	92°41′28.7″	Good	Mud line in utility shelter	BARN3	USGS
1,088.2	46°29′42.2″	92°41′32.2″	--	--	MR5	USACE St. Paul District
				Carlton		
1,084.1	46°39′47.6″	92°25′54.5″	Good	Mud line on storage container	CARL1	USGS
1,083.4	46°39′46.1″	92°25′45″	Poor	Debris line on fence	CARL2	USGS
1,082.8	46°39′44.7″	92°25′40.1″	Good	Mud line on propane tank	CARL3	USGS
1,082.7	46°39′42.3″	92°25′29.6″	Good	Mud line on Carlton City wastewater treatment plant	CARL4	USGS
1,081.9	46°39′41.9″	92°25′25.6″	Good	Mud line on Carlton City equipment garage	CARL5	USGS
1,081.7	46°39′41.8″	92°25′23.9″	Good	Mud line on house	CARL6	USGS
1,081.7	46°39′42.9″	92°25′22.7″	Good	Mud line on shed	CARL7	USGS
1,081.5	46°39′41.9″	92°25′22.2″	Good	Mud line on house	CARL8	USGS
1,081.9	46°39′50.1″	92°25′45.4″	Good	Mud line on laundry building	CARL9	USGS
1,080.8	46°39′49.5″	92°25′35.8″	Good	Mud line in car shop	CARL10	USGS
1,081.0	46°39′49.5″	92°25′35.8″	Good	Mud line in car shop	CARL11	USGS
1,079.7	46°39′52.4″	92°25′38.6″	Good	Mud line on garage	CARL12	USGS
1,080.0	46°39′54.8″	92°25′37.7″	Good	Mud line on shed	CARL13	USGS
1,079.6	46°39′56.1″	92°25′34.1″	Poor	Mud line on propane tank	CARL14	USGS
1,080.1	46°39′56.8″	92°25′34.6″	Poor	Mud line on house	CARL15	USGS
1,078.2	46°39′57.6″	92°25′31.9″	Poor	As shown by onsite person, line on driveway	CARL16	USGS
1,077.5	46°39′58.2″	92°25′32.1″	Poor	Grass line in trees	CARL17	USGS
1,077.5	46°39′59.9″	92°25′31.7″	Good	Mud line on garage	CARL18	USGS
1,076.9	46°40′0.1″	92°25′32.2″	Fair	Grass line on bushes	CARL19	USGS
				Duluth Heights, Duluth		
1,320.1	46°48′26.2″	92°9′57.8″	Good	Mud line on building	MIL1	City of Duluth; USACE Detroit District
1,320.0	46°48′26″	92°9′53.2″	Poor	Mud line on building	MIL2	City of Duluth; USACE Detroit District
1,320.0	46°48′20.1″	92°9′56.7″	Poor	As shown by onsite person	MIL3	City of Duluth; USACE Detroit District
1,319.9	46°48′18.9″	92°9′49.3″	Fair	Mud line on guard rail	MIL4	City of Duluth; USACE Detroit District
1,320.4	46°48′29.8″	92°10′2.1″	Fair	As shown by onsite person	MIL5	City of Duluth; USACE Detroit District
1,338.8	46°48′45.1″	92°10′25.5″	Fair	As shown by onsite person	MIL6	City of Duluth; USACE Detroit District
1,337.9	46°49′0.4″	92°10′32.4″	Fair	As shown by onsite person	MIL7	City of Duluth; USACE Detroit District
1,340.1	46°49′1.9″	92°10′39.2″	Fair	As shown by onsite person	MIL8	City of Duluth; USACE Detroit District
1,348.3	46°49′17.3″	92°10′35.4″	Fair	Mud line	MIL10	City of Duluth; USACE Detroit District
1,320.4	46°48′30.9″	92°9′48.2″	Good	Mud line in building	MIL11	City of Duluth; USACE Detroit District

Table 1–1. High-water-mark descriptions for the mapped communities of Barnum, Carlton, Duluth Heights neighborhood in Duluth, Fond du Lac neighborhood in Duluth, Moose Lake, and Thomson for the floods of June 2012 in northeastern Minnesota.—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. Approximate quality ratings of high-water marks: Excellent, plus or minus (±) 0.02 foot; Good, ± 0.05 foot; Fair, ± 0.1 foot; and Poor, greater than 0.10 foot (Lumia and others, 1986).°, degrees; ′, minutes; ″, seconds; --, not available; USACE, U.S. Army Corps of Engineers; USGS, U.S. Geological Survey]

Elevation (feet above NAVD 88)	Latitude	Longitude	High-water-mark quality	High-water-mark description	High-water-mark identifier	Agency that collected data
				Fond du Lac, Duluth		
611.6	46°39′40.5″	92°17′4″	Fair	Mud line on power pole next to river	FDL1	USGS
608.5	46°39′39.3″	92°16′58.6″	Poor	Mud line on grass in park	FDL2	USGS
610.2	46°39′35″	92°16′41.4″	Fair	Mud line on red shed	FDL3	USGS
608.5	46°39′35.5″	92°16′38.1″	Fair	Mud line on shed	FDL4	USGS
607.6	46°39′36″	92°16′37.1″	Fair	Grass line on garage	FDL5	USGS
606.8	46°39′33.5″	92°16′37.4″	Fair	Mud line on shed	FDL6	USGS
607.1	46°39′33.8″	92°16′36.7″	Fair	Mud line on shed	FDL7	USGS
609.2	46°39′34.7″	92°16′36.3″	Poor	Grass line on fence	FDL8	USGS
613.5	46°39′40.3″	92°16′26.6″	Poor	Grass line on fence	FDL9	USGS
609.3	46°39′25.4″	92°16′22.1″	Good	Mud line on house	FDL10	USGS
609.5	46°39′16.7″	92°16′22.3″	Good	Seed line on shed	FDL11	USGS
609.3	46°39′16.4″	92°16′22.1″	Fair	Grass line on fence	FDL12	USGS
608.9	46°39′16.1″	92°16′22.1″	Fair	Mud line on house	FDL13	USGS
608.7	46°39′5.6″	92°16′14.4″	Good	Grass line on house	FDL14	USGS
				Moose Lake		
1,052.5	46°27′27.4″	92°45′4.4″	--	--	MR3	USACE St. Paul District
1,048.2	46°27′6.2″	92°44′46.4″	Good	Mud line on paved trail	MOOSE1	USGS
1,049.2	46°27′4.4″	92°44′46.3″	Fair	Mud line on paved trail	MOOSE2	USGS
1,053.3	46°27′23.2″	92°45′24.3″	Poor	Debris line in tree	MOOSE3	USGS
1,052.8	46°27′2.4″	92°45′34.7″	Good	Mud line on building	MOOSE4	USGS
1,052.5	46°26′30″	92°45′40.9″	Good	Debris line on ground	MOOSE5	USGS
1,052.9	46°26′46.2″	92°46′6.9″	Fair	Scratch mark on bridge rail	MOOSE6	USGS
1,052.9	46°26′46.2″	92°46′6.9″	Fair	Scratch mark on bridge rail	MOOSE7	USGS
1,052.1	46°26′45.7″	92°46′7.3″	--	--	MR2	USACE St. Paul District
1,050.8	46°26′50.3″	92°46′17.2″	Good	Mud line on building	MOOSE8	USGS
1,042.9	46°26′38.7″	92°46′34.4″	Poor	Debris line on ground	MOOSE9	USGS
				Thomson		
1,054.9	46°39′49.7″	92°23′27.7″	Good	Mud line on garage	ETHOM1	USGS
1,054.9	46°39′47.9″	92°23′26.8″	Good	Mud line on house	ETHOM2	USGS
1,072.0	46°39′59.9″	92°23′56.6″	Poor	Seed/Grass line on tree	THOM1	USGS
1,071.0	46°39′59.7″	92°23′57.1″	Poor	Seed/Grass line in tree	THOM2	USGS
1,064.9	46°39′58.5″	92°23′59.8″	Poor	Mud line behind studio	THOM3	USGS
1,063.0	46°39′58.4″	92°23′59″	Poor	Mud line on front of studio	THOM4	USGS
1,062.6	46°39′58.1″	92°23′59.8″	Poor	Debris line in grass	THOM5	USGS
1,061.5	46°39′57.4″	92°23′56.5″	Poor	As shown by onsite person, on step next to brick planter	THOM6	USGS
1,050.5	46°39′54.6″	92°23′57.7″	Poor	Debris caught in fence	THOM7	USGS
1,047.2	46°39′52.6″	92°23′57.4″	Poor	Debris line in tree	THOM8	USGS
1,048.6	46°39′52″	92°23′56.6″	Fair	Debris line in power pole	THOM9	USGS
1,046.9	46°39′52.3″	92°24′0.1″	Poor	Debris line at base of stake	THOM10	USGS
1,046.1	46°39′48.9″	92°23′57.6″	Good	Mud line on pump house	THOM11	USGS
1,036.0	46°39′47.4″	92°24′0.4″	Poor	Debris at culvert under bike path	THOM12	USGS
1,041.1	46°39′47.2″	92°23′59.8″	Poor	Debris line in trees	THOM13	USGS

Table 1–2. Descriptions of additional high-water marks for the floods of June 2012 in northeastern Minnesota.

[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. Approximate quality ratings of high-water marks: Excellent, ± 0.02 foot; Good, ± 0.05 foot; Fair, ± 0.1 foot; and Poor, greater than 0.10 foot (Lumia and others, 1986). °, degrees; ′, minutes; ″, seconds; USACE, U.S. Army Corps of Engineers; --, not available]

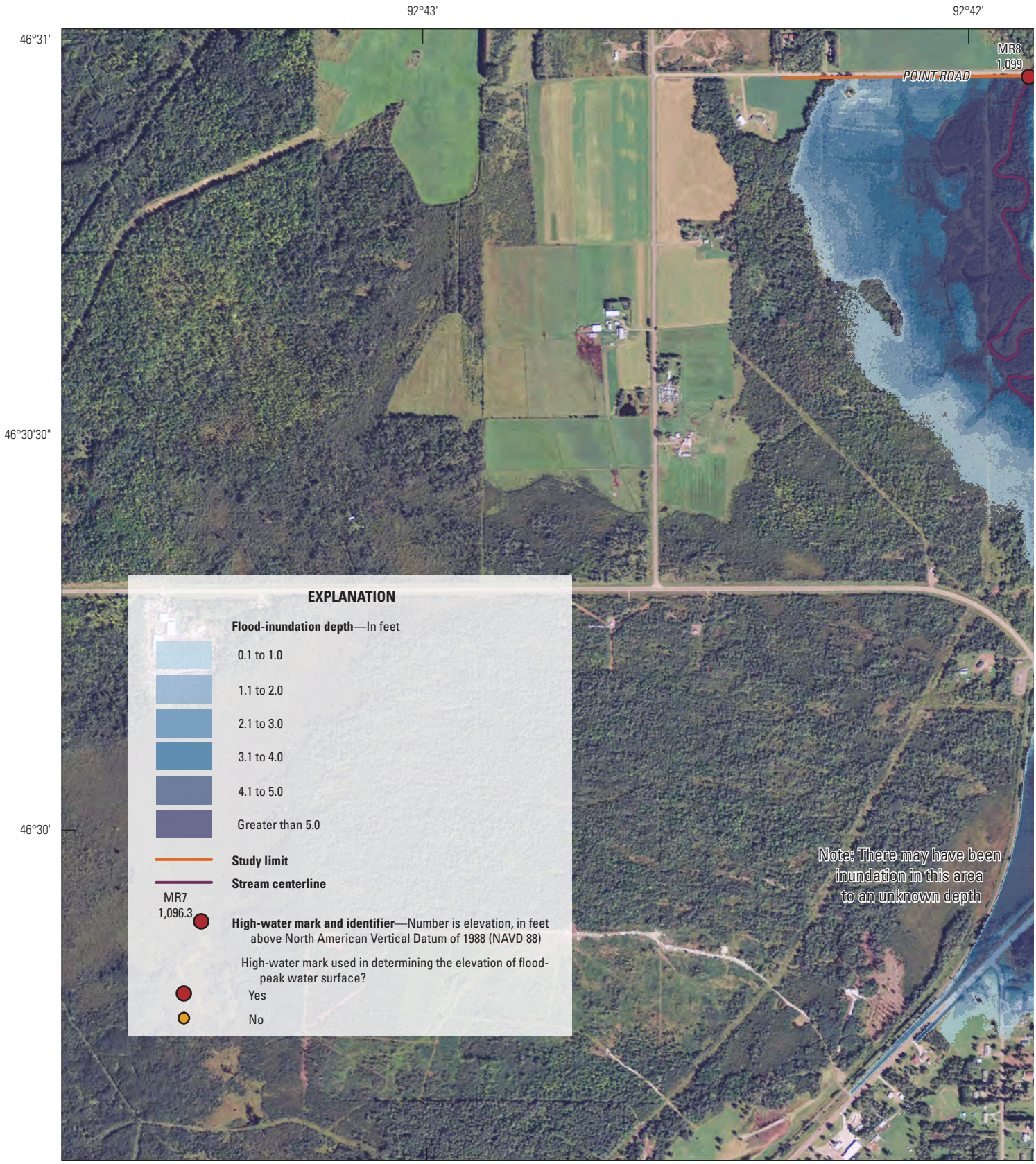
Elevation (feet above NAVD 88)	Latitude	Longitude	High-water-mark quality	High-water-mark description	High-water-mark identifier	Agency that collected data
				Keene Creek		
616.7	46°43′58.1″	92°10′5.7″	Good	Debris line on fence	KEE1	City of Duluth; USACE Detroit District
615.8	46°43′56.2″	92°10′8.6″	Fair	Debris line at creek	KEE2	City of Duluth; USACE Detroit District
605.9	46°43′58.3″	92°9′34″	Excellent	Debris line on fence	KEE3	City of Duluth; USACE Detroit District
614.8	46°43′59.4″	92°10′16.6″	Good	Mud line on building	KEE5	City of Duluth; USACE Detroit District
622.5	46°44′0.4″	92°10′21.3″	Good	Mud line on structure	KEE6	City of Duluth; USACE Detroit District
624.6	46°44′1.6″	92°10′24.3″	Good	Debris line on fence	KEE7	City of Duluth; USACE Detroit District
654.2	46°44′15.6″	92°10′39.4″	Good	Debris line	KEE9	City of Duluth; USACE Detroit District
651.3	46°44′15.5″	92°10′35.1″	Poor	Mud line on street	KEE10	City of Duluth; USACE Detroit District
				Kettle River		
1,029.8	46°16′6.1″	92°51′41.2″	--	Approximate Coordinates	KR1	USACE St. Paul District
1,036.6	46°18′22.5″	92°51′42.1″	--	Approximate Coordinates	KR2	USACE St. Paul District
1,038.8	46°19′35.6″	92°50′51.8″	--	Approximate Coordinates	KR3	USACE St. Paul District
1,044.5	46°21′38.9″	92°50′33.6″	--	Approximate Coordinates	KR4	USACE St. Paul District
				Kingsbury Creek		
1,237.6	46°44′37.4″	92°13′26.6″	Good	As shown by onsite person	KIN1	City of Duluth; USACE Detroit District
1,248.8	46°44′53.9″	92°13′18.5″	Good	As shown by onsite person	KIN2	City of Duluth; USACE Detroit District
1,248.7	46°44′52.9″	92°13′20.8″	Fair	Mud line on structure. As shown by onsite person	KIN3	City of Duluth; USACE Detroit District
1,238.3	46°44′47.6″	92°13′26.8″	Good	As shown by onsite person	KIN4	City of Duluth; USACE Detroit District
1,238.6	46°44′49.4″	92°13′27″	Good	As shown by onsite person	KIN5	City of Duluth; USACE Detroit District
1,236.5	46°44′44.7″	92°13′28.3″	Poor	As shown by onsite person	KIN6	City of Duluth; USACE Detroit District
1,238.4	46°44′45″	92°13′26.7″	--	--	KIN7	City of Duluth; USACE Detroit District
1,235.2	46°44′40.5″	92°13′42″	Fair	As shown by onsite person	KIN8	City of Duluth; USACE Detroit District
1,236.2	46°44′47.6″	92°13′48.9″	Good	As shown by onsite person	KIN9	City of Duluth; USACE Detroit District
1,247.6	46°44′56.4″	92°14′17.6″	Good	As shown by onsite person	KIN10	City of Duluth; USACE Detroit District
1,230.2	46°44′32.1″	92°13′34.1″	Good	As shown by onsite person	KIN11	City of Duluth; USACE Detroit District
1,229.0	46°44′25.2″	92°13′37.4″	Good	As shown by onsite person	KIN12	City of Duluth; USACE Detroit District
630.9	46°43′31.1″	92°11′32″	Good	As shown by onsite person	KIN13	City of Duluth; USACE Detroit District
631.7	46°43′28.4″	92°11′33.9″	Good	As shown by onsite person	KIN14	City of Duluth; USACE Detroit District
633.0	46°43′27.1″	92°11′27.8″	Good	As shown by onsite person	KIN15	City of Duluth; USACE Detroit District
629.1	46°43′31.3″	92°11′22.7″	Good	As shown by onsite person	KIN16	City of Duluth; USACE Detroit District
				Miller Creek		
652.6	46°45′54.3″	92°7′59.5″	Good	Debris line at bridge	LWMIL14	City of Duluth; USACE Detroit District
652.8	46°45′53.1″	92°8′2.1″	Good	Debris line at bridge	LWMIL15	City of Duluth; USACE Detroit District
644.1	46°45′50.7″	92°7′57″	Good	Mud line on building	LWMIL16	City of Duluth; USACE Detroit District
640.1	46°45′48.1″	92°8′0.5″	Poor	As shown by onsite person	LWMIL17	City of Duluth; USACE Detroit District
639.3	46°45′46.3″	92°7′58.8″	Fair	Mud line on post	LWMIL19	City of Duluth; USACE Detroit District
				Mississippi River		
1,219.8	46°47′31.8″	93°19′36.7″	--	--	MIS1	USACE St. Paul District
1,221.4	46°47′17.8″	93°19′16″	--	--	MIS2	USACE St. Paul District
1,220.0	46°47′11.1″	93°19′28.9″	--	--	MIS3	USACE St. Paul District
1,217.5	46°46′13.8″	93°23′12.4″	--	--	MIS4	USACE St. Paul District
1,214.9	46°43′51.9″	93°26′56.2″	--	--	MIS5	USACE St. Paul District
1,212.8	46°42′39.4″	93°28′42.4″	--	--	MIS6	USACE St. Paul District
1,212.6	46°42′34.9″	93°29′8.3″	--	--	MIS7	USACE St. Paul District

Table 1–2. Descriptions of additional high-water marks for the floods of June 2012 in northeastern Minnesota.—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. Approximate quality ratings of high-water marks: Excellent, ± 0.02 foot; Good, ± 0.05 foot; Fair, ± 0.1 foot; and Poor, greater than 0.10 foot (Lumia and others, 1986). °, degrees; ′, minutes; ″, seconds; USACE, U.S. Army Corps of Engineers; --, not available]

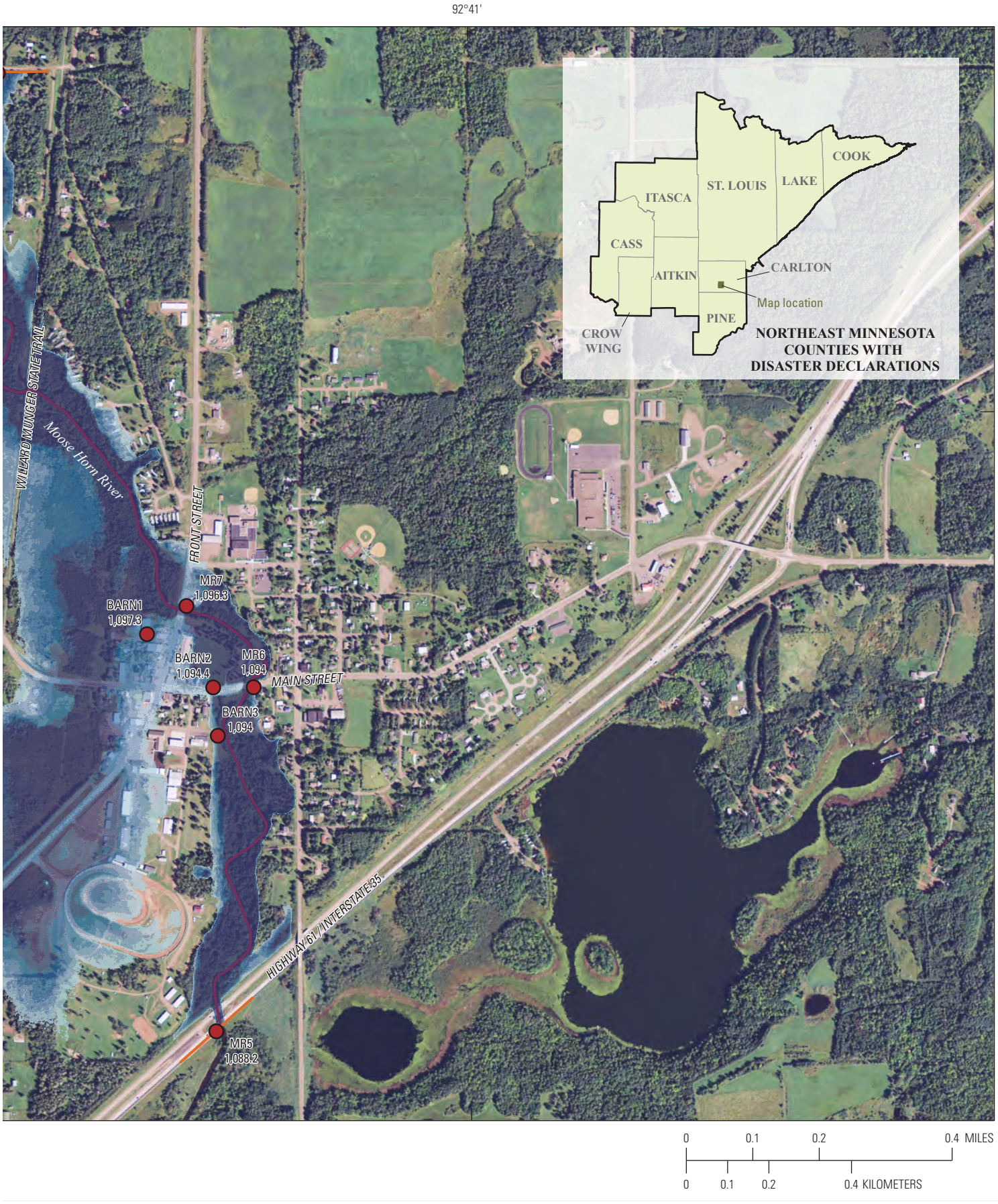
Elevation (feet above NAVD 88)	Latitude	Longitude	High-water-mark quality	High-water-mark description	High-water-mark identifier	Agency that collected data
				Mississippi River—Continued		
1,210.5	46°41′21.3″	93°32′47″	--	--	MIS8	USACE St. Paul District
1,209.7	46°40′41.5″	93°36′2.8″	--	Overland flow crossing road probably from Willow River	MIS9	USACE St. Paul District
1,209.1	46°40′23.2″	93°36′17.9″	--	--	MIS10	USACE St. Paul District
1,207.7	46°39′6.2″	93°36′44.9″	--	--	MIS11	USACE St. Paul District
1,205.8	46°37′30.5″	93°38′45.5″	--	--	MIS12	USACE St. Paul District
1,203.3	46°35′23.5″	93°39′53.6″	--	--	MIS13	USACE St. Paul District
1,202.1	46°33′42.6″	93°41′47.3″	--	Flood debris / silt line on tree	MIS14	USACE St. Paul District
1,202.1	46°34′46.8″	93°42′25.4″	--	--	MIS15	USACE St. Paul District
1,200.6	46°32′47.8″	93°42′26.5″	--	--	MIS16	USACE St. Paul District
1,201.0	46°32′31.7″	93°42′26.7″	--	--	MIS17	USACE St. Paul District
1,201.2	46°32′28.6″	93°42′22.9″	--	--	MIS18	USACE St. Paul District
1,201.4	46°32′27.2″	93°42′28″	--	--	MIS19	USACE St. Paul District
1,200.1	46°32′51″	93°46′32.6″	--	--	MIS20	USACE St. Paul District
1,199.1	46°34′44.1″	93°47′31.2″	--	Debris line, edge of field, right side of house past electric fence	MIS21	USACE St. Paul District
1,199.3	46°35′3.3″	93°48′6.9″	--	--	MIS22	USACE St. Paul District
1,199.0	46°35′6.6″	93°48′55.9″	--	--	MIS23	USACE St. Paul District
1,197.1	46°34′13.8″	93°52′25.4″	--	--	MIS25	USACE St. Paul District
1,193.0	46°32′38.5″	93°57′20.3″	--	--	MIS26	USACE St. Paul District
				Mississippi River Diversion Channel		
1,202.6	46°35′23.5″	93°39′53.6″	--	--	DC1	USACE St. Paul District
1,203.0	46°35′23.5″	93°39′53.6″	--	--	DC2	USACE St. Paul District
1,202.2	46°35′31″	93°41′12.6″	--	--	DC3	USACE St. Paul District
1,200.1	46°35′34.7″	93°45′38.5″	--	--	DC4	USACE St. Paul District
				Moose Horn River		
1,043.6	46°22′57.5″	92°50′27.9″	--	--	MR1	USACE St. Paul District
1,044.5	46°22′56.8″	92°50′1.7″	--	Approximate coordinates	MR1A	USACE St. Paul District
1,081.7	46°28′37.7″	92°42′47.4″	--	--	MR4	USACE St. Paul District
1,113.4	46°31′10.3″	92°42′34.3″	--	--	MR9	USACE St. Paul District
1,147.7	46°31′9.9″	92°43′43″	--	--	MR10	USACE St. Paul District
				Pine River		
1,028.5	46°15′17.1″	92°51′58.3″	--	Approximate coordinates	PR1	USACE St. Paul District
1,033.4	46°15′34.3″	92°53′37.8″	--	Approximate coordinates	PR2	USACE St. Paul District
1,043.1	46°16′22.1″	92°54′28.1″	--	Approximate coordinates	PR3	USACE St. Paul District
1,071.6	46°18′12.7″	92°54′28.7″	--	Approximate coordinates	PR4	USACE St. Paul District
1,072.7	46°18′36.6″	92°54′28.2″	--	Approximate coordinates. Water on road	PR5	USACE St. Paul District
				Willow River		
1,038.5	46°19′24.9″	92°50′21.5″	--	Approximate coordinates	WR1	USACE St. Paul District

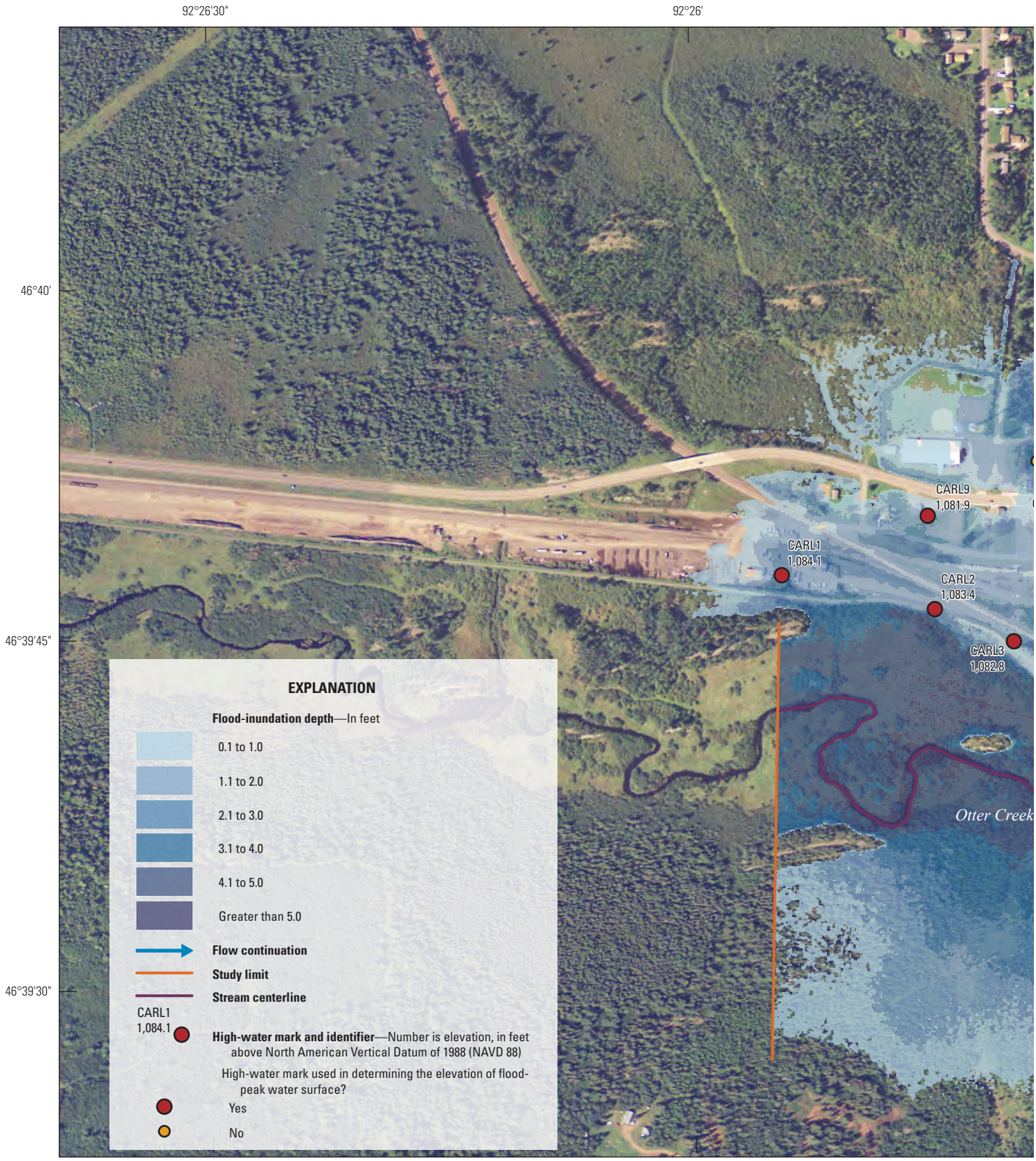
Appendix 2. Flood-Peak Inundation Maps



Aerial photograph courtesy of MNGEO, Spatial Data Portal, 2010 National Agriculture Imagery Program, accessed December 2012, at *http://www.mngeo.state.mn.us/chouse/metadata/naip10.html*
Universal Transverse Mercator projection, Zone 15

Figure 2–1. Approximate extent and depth of flood-peak inundation, flood of June 2012, for the Moose Horn River at Barnum, Minnesota.

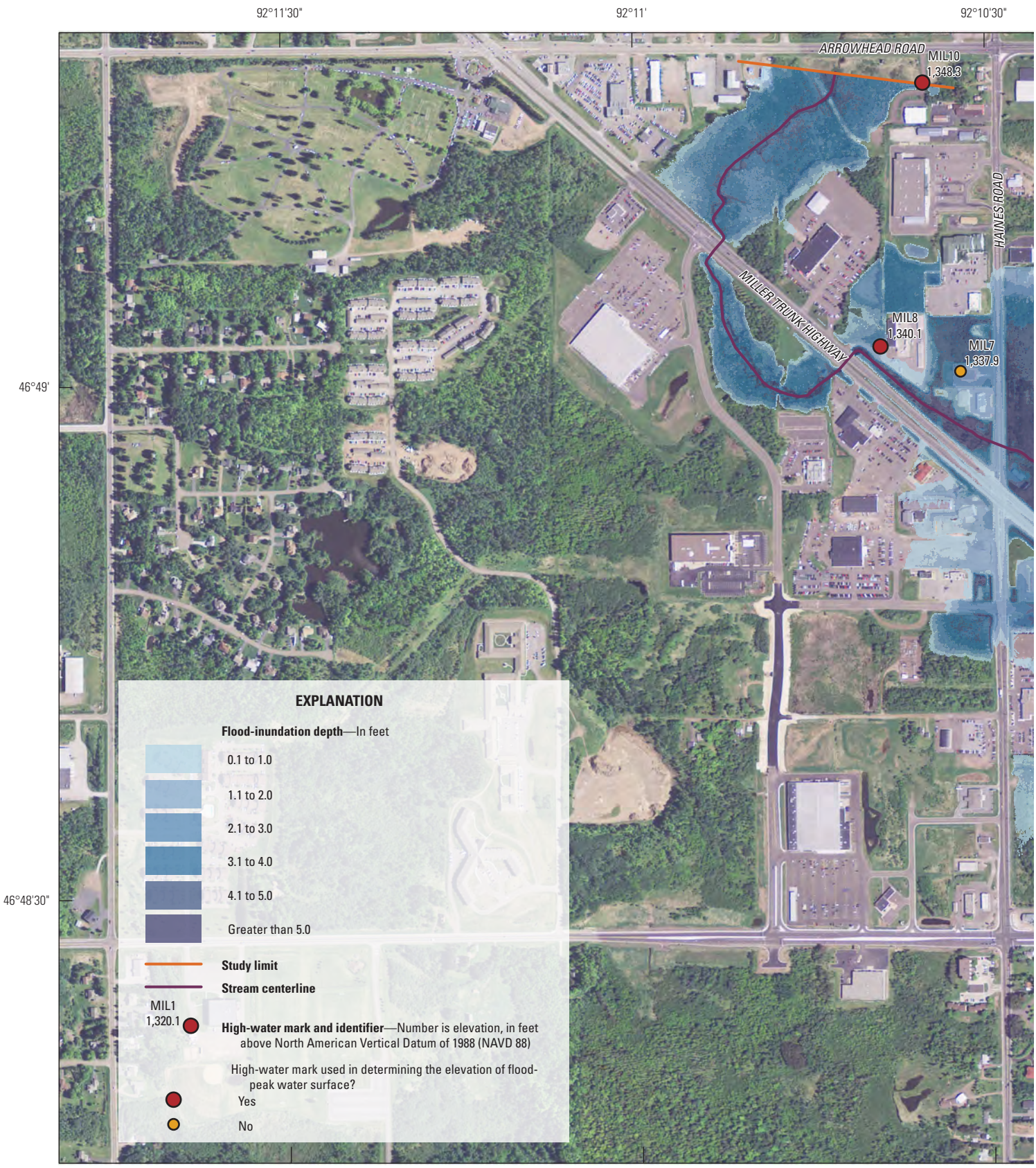

92°41'
WILLARD MUNGER STATE TRAIL
Moose Horn River
FRONT STREET
MAIN STREET
HIGHWAY 61 / INTERSTATE 35
MR7
1,096.3
BARN1
1,097.3
BARN2
1,094.4
MR6
1,094
BARN3
1,094
MR5
1,088.2
COOK
LAKE
ST. LOUIS
ITASCA
CASS
AITKIN
CARLTON
Map location
PINE
CROW WING
NORTHEAST MINNESOTA COUNTIES WITH DISASTER DECLARATIONS
0 0.1 0.2 0.4 MILES
0 0.1 0.2 0.4 KILOMETERS



Aerial photograph courtesy of MNGEO, Spatial Data Portal, 2010 National Agriculture Imagery Program, accessed December 2012, at *http://www.mngeo.state.mn.us/chouse/metadata/naip10.html*
Universal Transverse Mercator projection, Zone 15

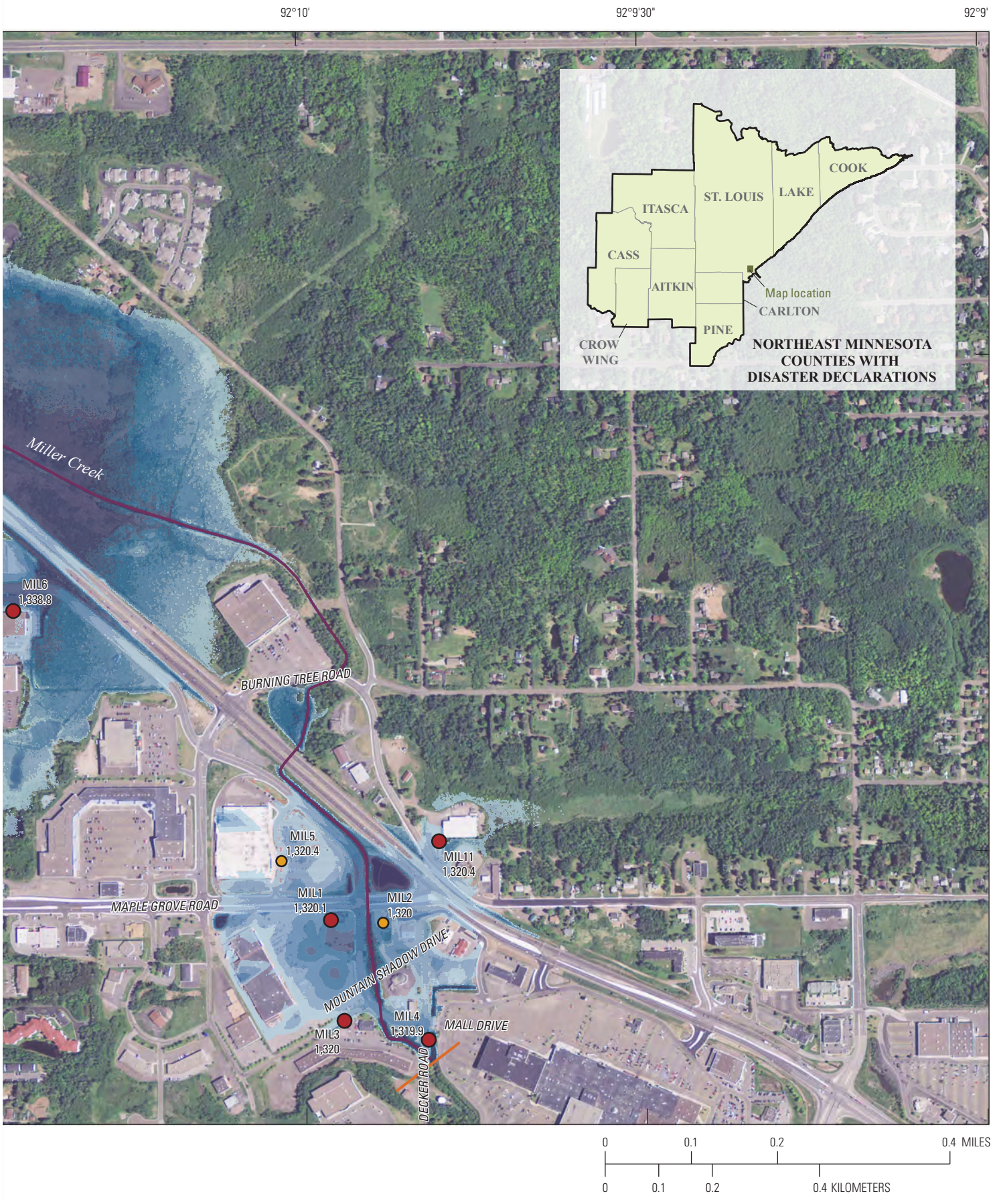
Figure 2–2. Approximate extent and depth of flood-peak inundation, flood of June 2012, for Otter Creek at Carlton, Minnesota.

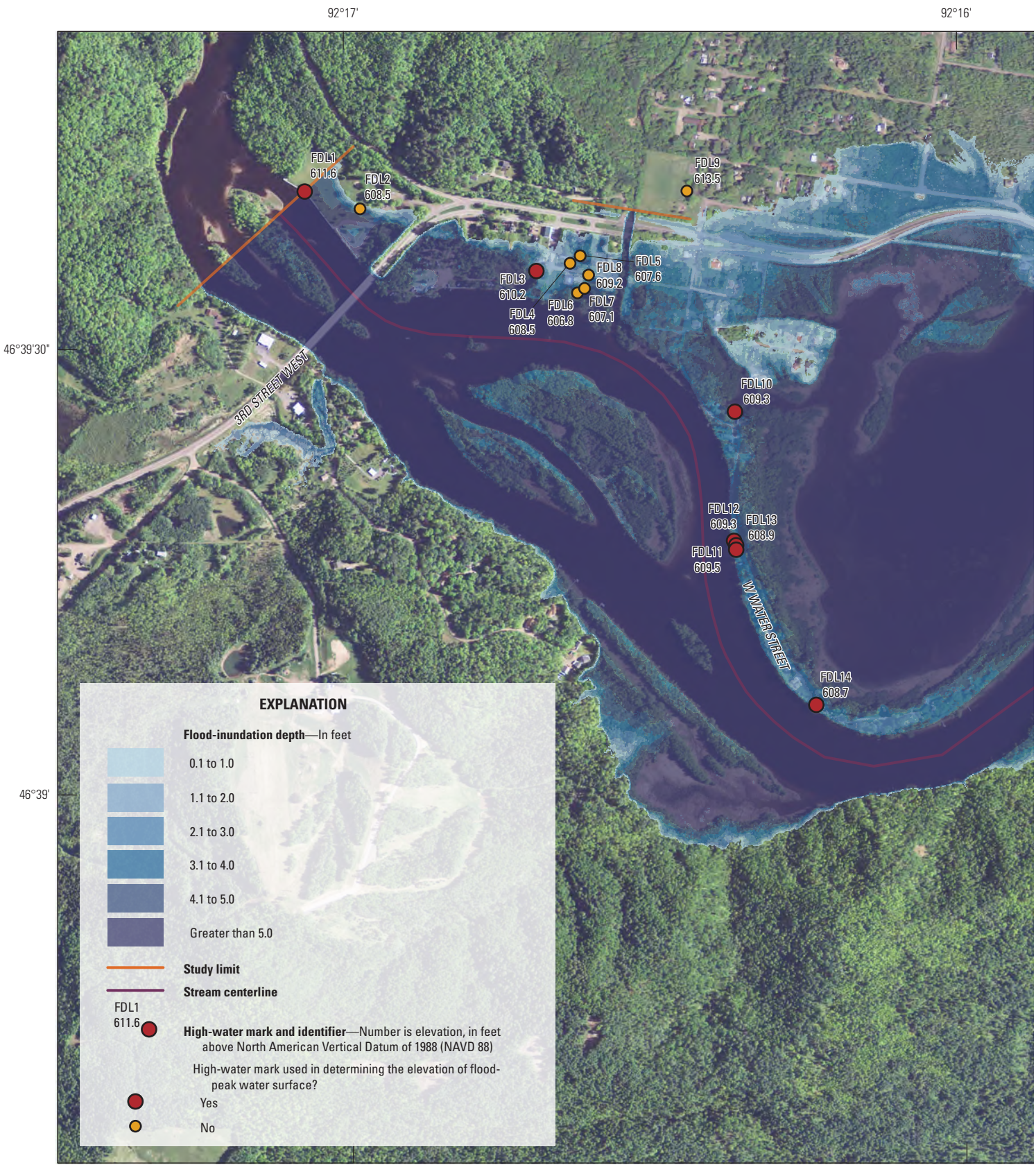
92°25'30"
92°25'
Thomson Reservoir
CARL19 1,076.9
CARL18 1,077.5
CARL17 1,077.5
CARL15 1,080.1
CARL16 1,078.2
CARL13 1,080
CARL14 1,079.6
CARL12 1,079.7
CARL10 1,080.8
CARL11 1,081
HIGHWAY 210
CARL4 1,082.7
CARL5 1,081.9
CARL7 1,081.7
CARL8 1,081.5
CARL6 1,081.7
COUNTY ROAD 1
WILLARD MUNGER STATE TRAIL
COOK
LAKE
ST. LOUIS
ITASCA
CASS
AITKIN
CARLTON
PINE
CROW WING
Map location
NORTHEAST MINNESOTA COUNTIES WITH DISASTER DECLARATIONS
0 0.1 0.2 0.4 MILES
0 0.1 0.2 0.4 KILOMETERS



Aerial photograph courtesy of MNGEO, Spatial Data Portal, 2010 National Agriculture Imagery Program, accessed December 2012, at *http://www.mngeo.state.mn.us/chouse/metadata/naip10.html*
Universal Transverse Mercator projection, Zone 15

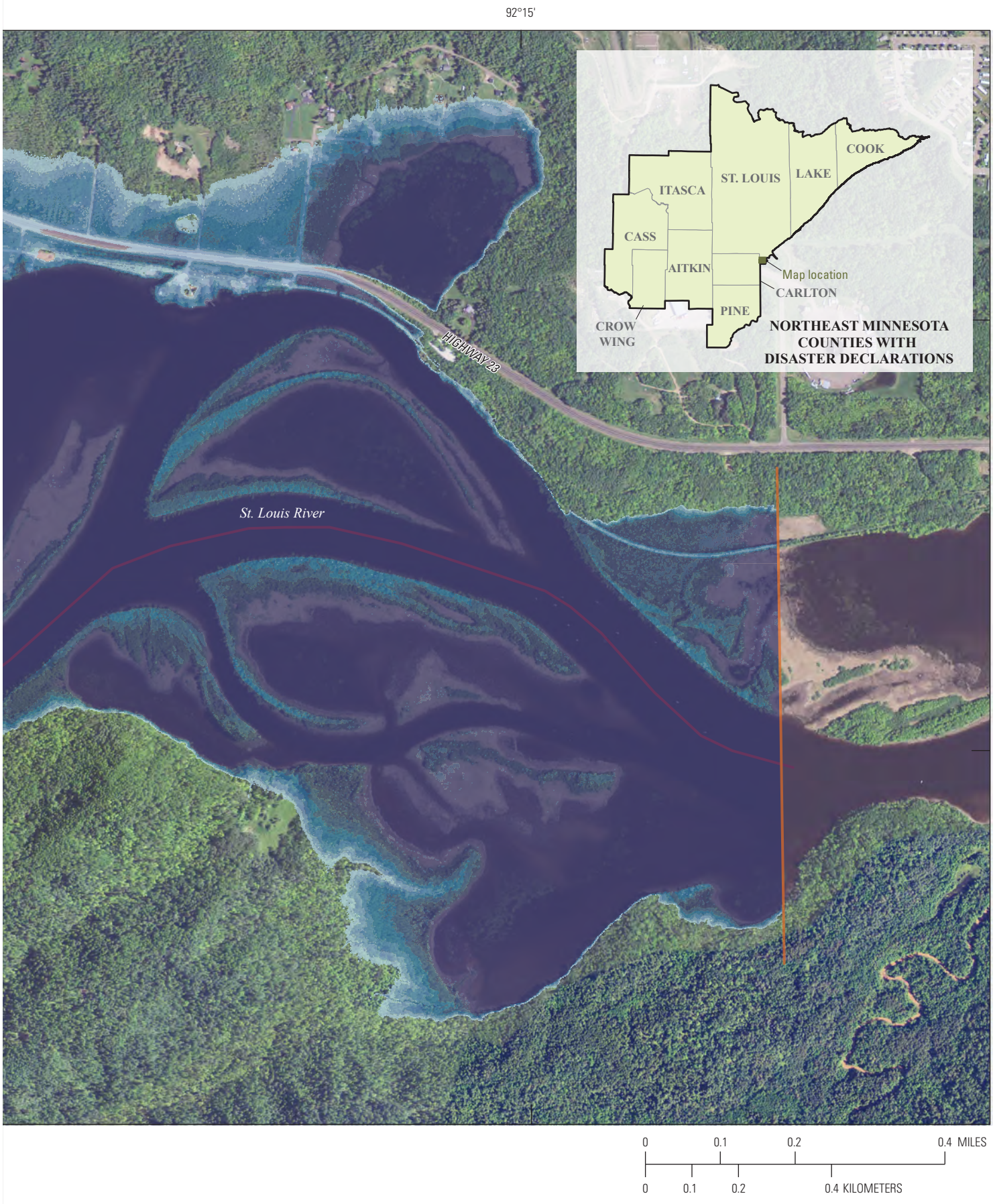
Figure 2–3. Approximate extent and depth of flood-peak inundation, flood of June 2012, for Miller Creek at the Duluth Heights neighborhood, Duluth, Minnesota.

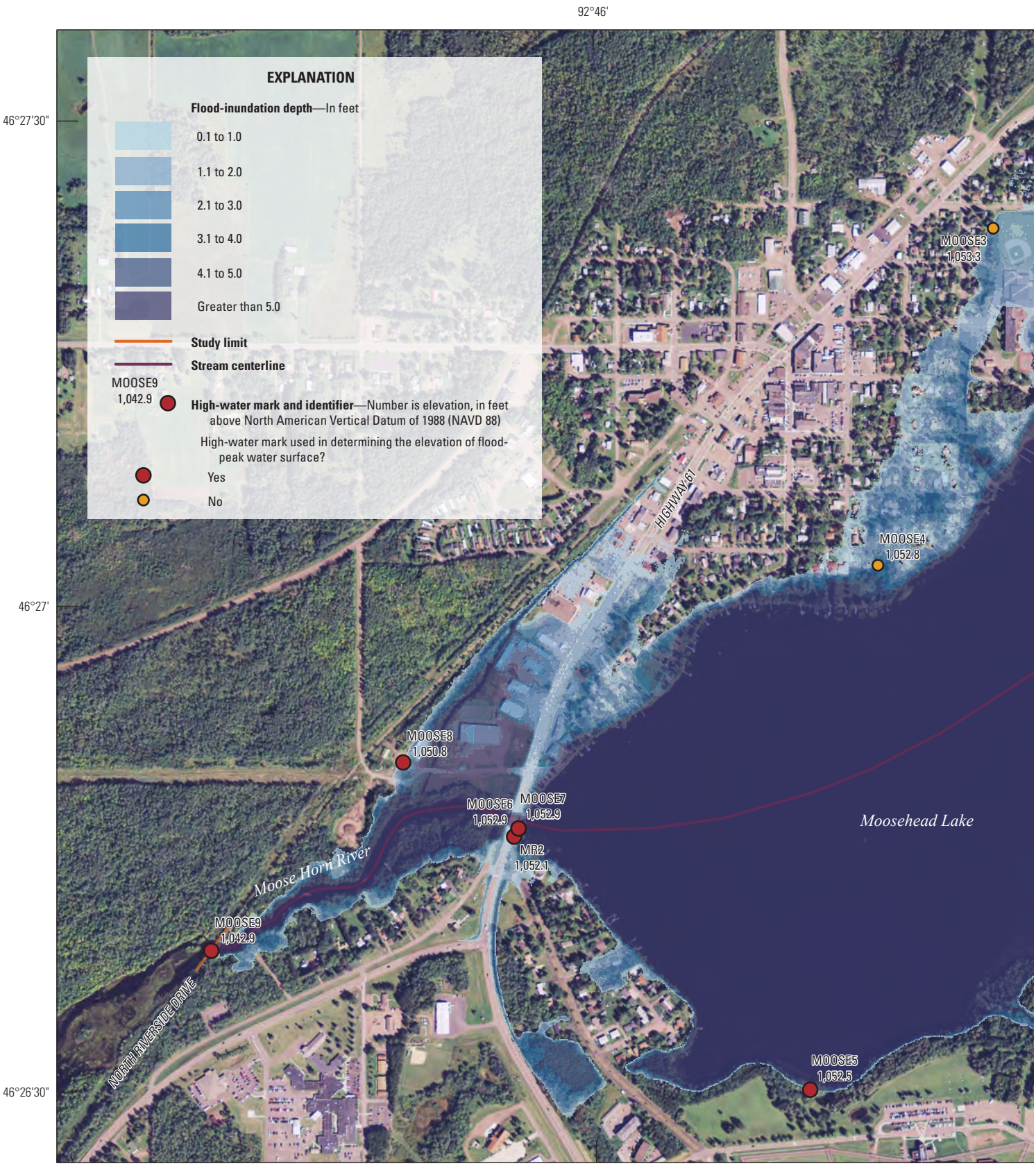

92°10'
92°9'30"
92°9'
COOK
LAKE
ST. LOUIS
ITASCA
CASS
AITKIN
PINE
CROW WING
Map location
CARLTON
NORTHEAST MINNESOTA COUNTIES WITH DISASTER DECLARATIONS
Miller Creek
MIL6
1,338.8
BURNING TREE ROAD
MIL5
1,320.4
MIL11
1,320.4
MIL1
1,320.1
MIL2
1,320
MAPLE GROVE ROAD
MOUNTAIN SHADOW DRIVE
MIL4
1,319.9
MALL DRIVE
MIL3
1,320
DECKER ROAD
0
0.1
0.2
0.4 MILES
0
0.1
0.2
0.4 KILOMETERS



Aerial photograph courtesy of MNGEO, Spatial Data Portal, 2010 National Agriculture Imagery Program, accessed December 2012, at *http://www.mngeo.state.mn.us/chouse/metadata/naip10.html*
Universal Transverse Mercator projection, Zone 15

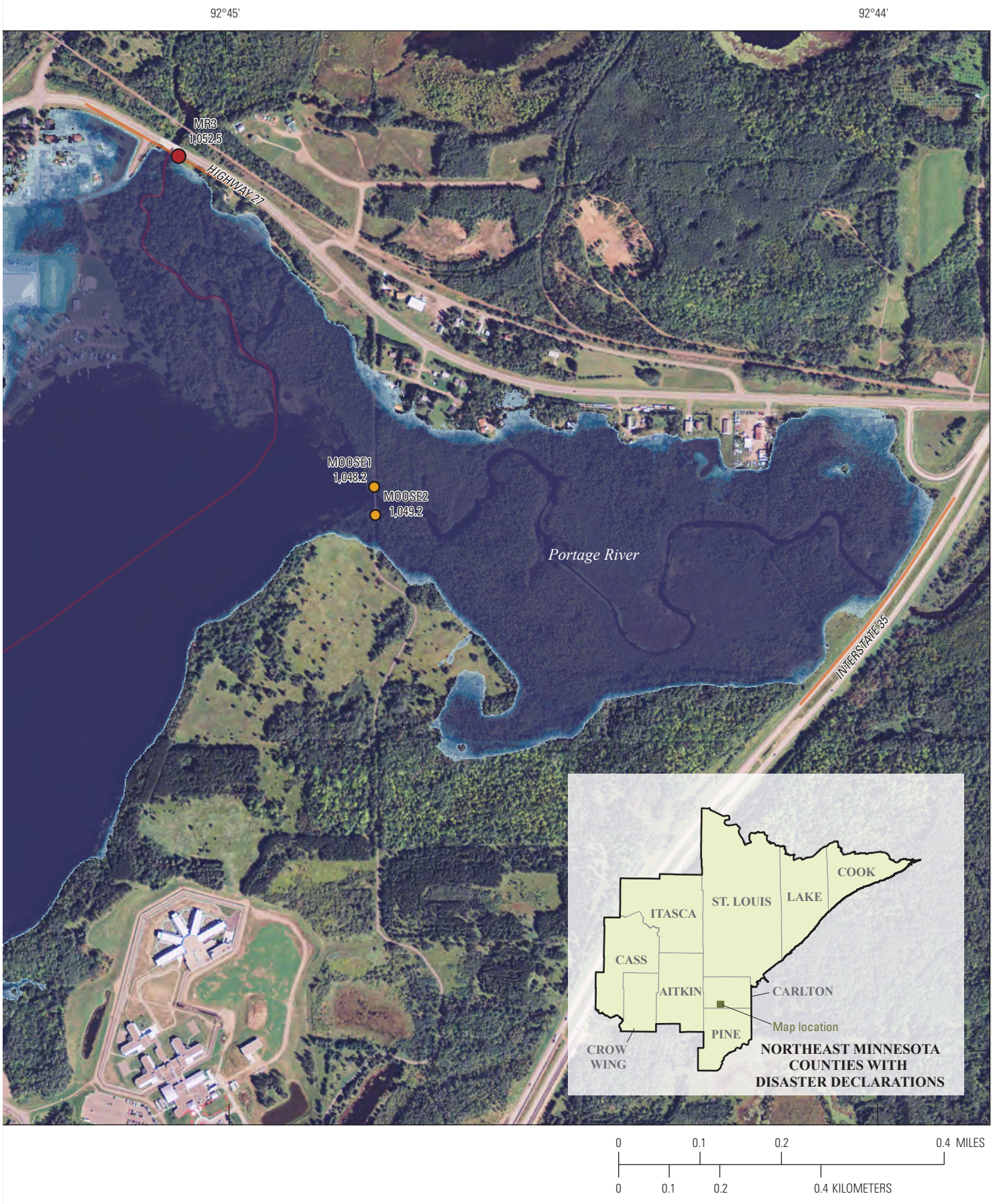
Figure 2–4. Approximate extent and depth of flood-peak inundation, flood of June 2012, for the St. Louis River at the Fond du Lac neighborhood, Duluth, Minnesota.

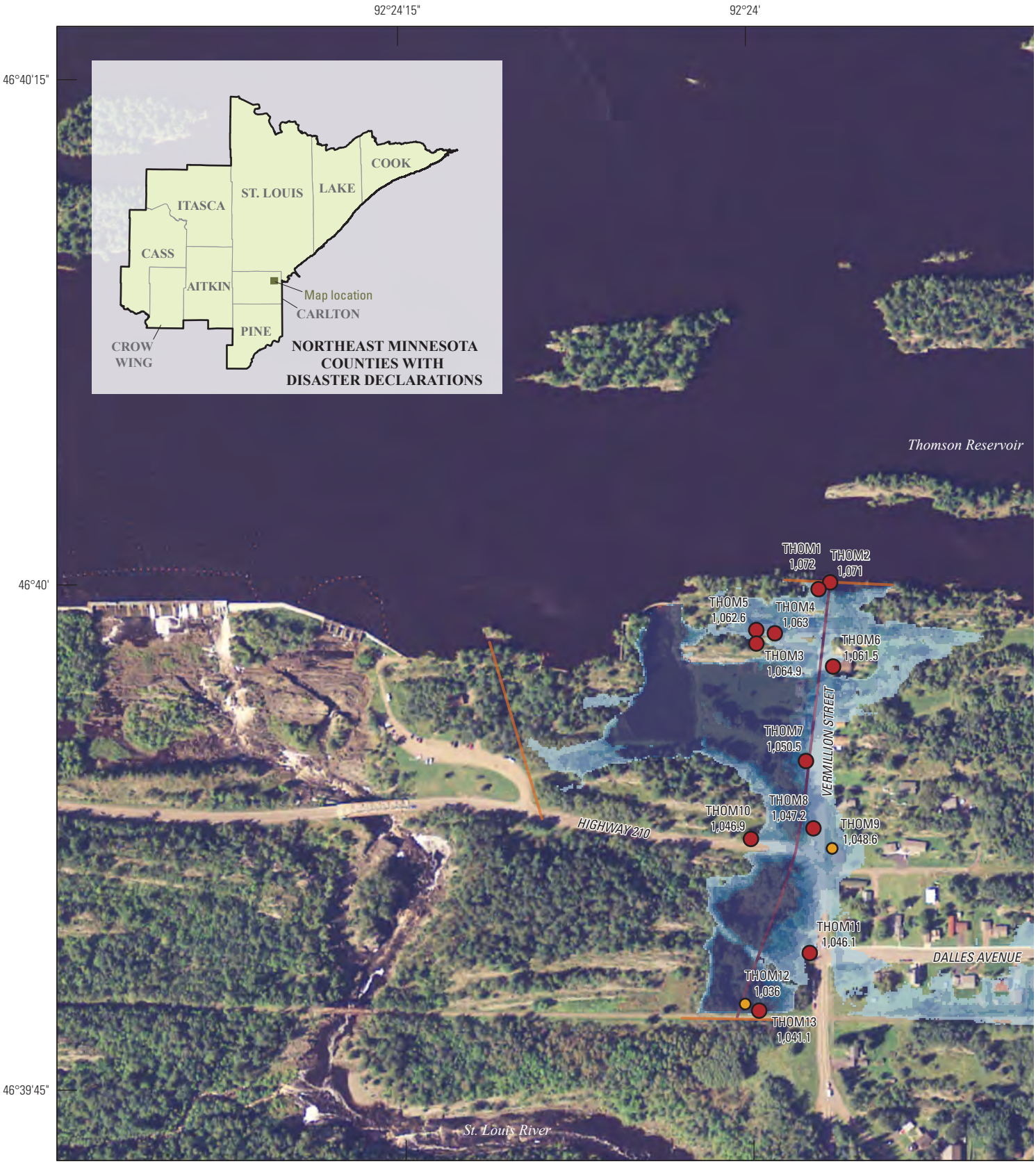

92°15'
COOK
LAKE
ST. LOUIS
ITASCA
CASS
AITKIN
PINE
CROW WING
CARLTON
Map location
NORTHEAST MINNESOTA COUNTIES WITH DISASTER DECLARATIONS
HIGHWAY 23
St. Louis River
0 0.1 0.2 0.4 MILES
0 0.1 0.2 0.4 KILOMETERS



Aerial photograph courtesy of MNGEO, Spatial Data Portal, 2010 National Agriculture Imagery Program, accessed December 2012, at *http://www.mngeo.state.mn.us/chouse/metadata/naip10.html*
Universal Transverse Mercator projection, Zone 15

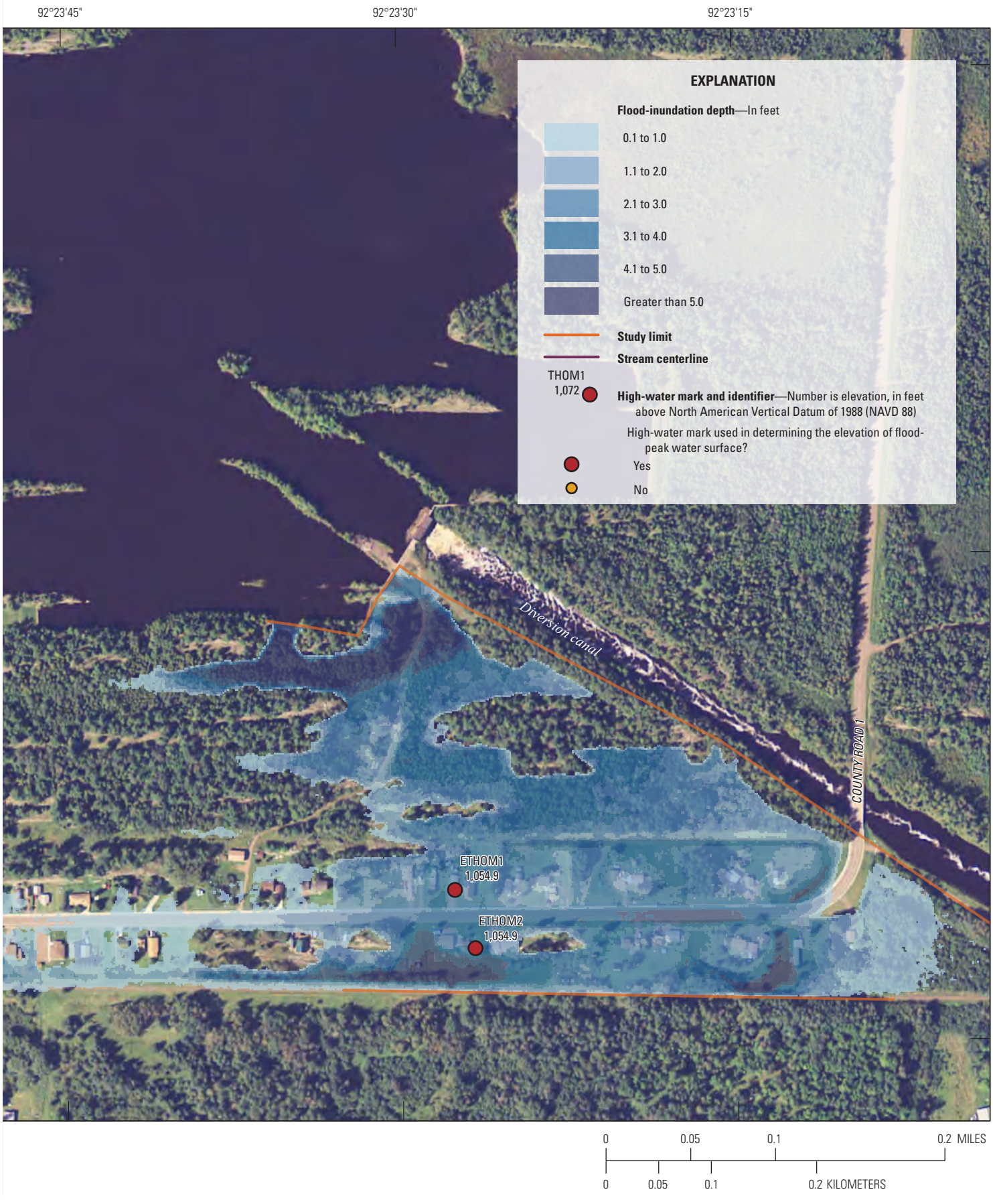
Figure 2–5. Approximate extent and depth of flood-peak inundation, flood of June 2012, for the Moose Horn River and Moosehead Lake at Moose Lake, Minnesota.


92°45'
92°44'
MR3
1,052.5
HIGHWAY 27
MOOSE1
1,048.2
MOOSE2
1,049.2
Portage River
INTERSTATE 35
COOK
LAKE
ST. LOUIS
ITASCA
CASS
AITKIN
CARLTON
PINE
CROW WING
Map location
NORTHEAST MINNESOTA COUNTIES WITH DISASTER DECLARATIONS
0
0.1
0.2
0.4 MILES
0
0.1
0.2
0.4 KILOMETERS



Aerial photograph courtesy of MNGEO, Spatial Data Portal, 2010 National Agriculture Imagery Program, accessed December 2012, at *http://www.mngeo.state.mn.us/chouse/metadata/naip10.html*
Universal Transverse Mercator projection, Zone 15

Figure 2–6. Approximate extent and depth of flood-peak inundation, flood of June 2012, for the Thomson Reservoir outflow near the St. Louis River at Thomson, Minnesota.


92°23'45"
92°23'30"
92°23'15"
EXPLANATION
Flood-inundation depth—In feet
0.1 to 1.0
1.1 to 2.0
2.1 to 3.0
3.1 to 4.0
4.1 to 5.0
Greater than 5.0
Study limit
Stream centerline
THOM1
1,072
High-water mark and identifier—Number is elevation, in feet above North American Vertical Datum of 1988 (NAVD 88)
High-water mark used in determining the elevation of flood-peak water surface?
Yes
No
Diversion canal
COUNTY ROAD 1
ETHOM1
1,054.9
ETHOM2
1,054.9
0
0.05
0.1
0.2 MILES
0
0.05
0.1
0.2 KILOMETERS

Appendix 3. Flood-Peak Water-Surface Profiles

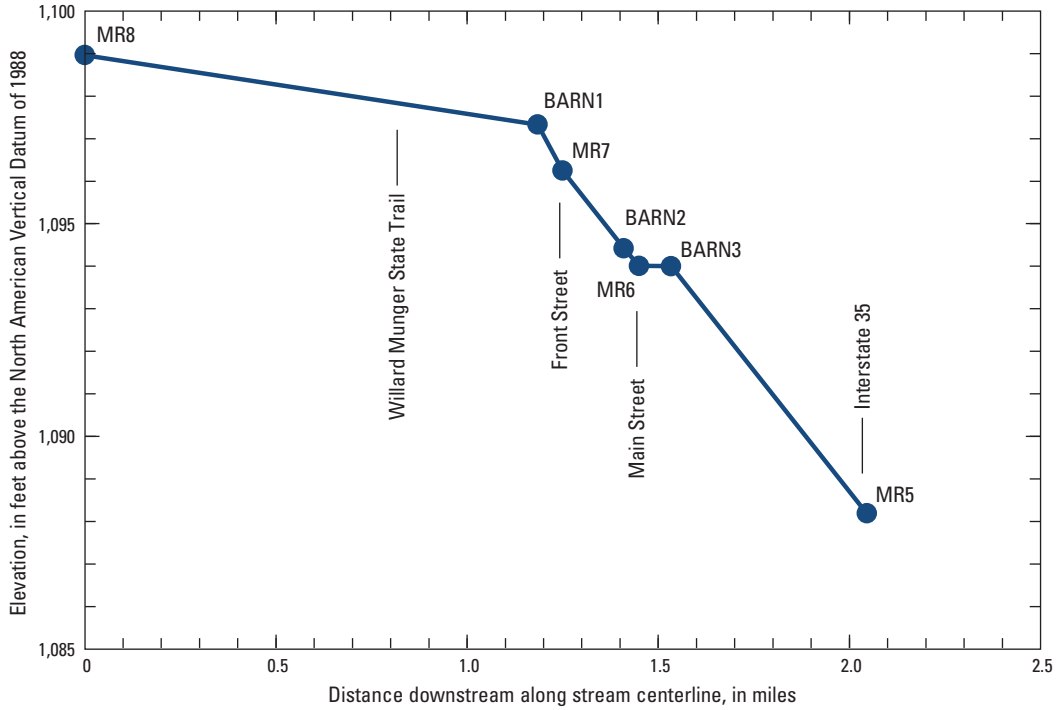


Figure 3–1. Flood-peak water-surface profile with selected high-water marks for the Moose Horn River at Barnum, Minnesota, for the flood of June 2012.

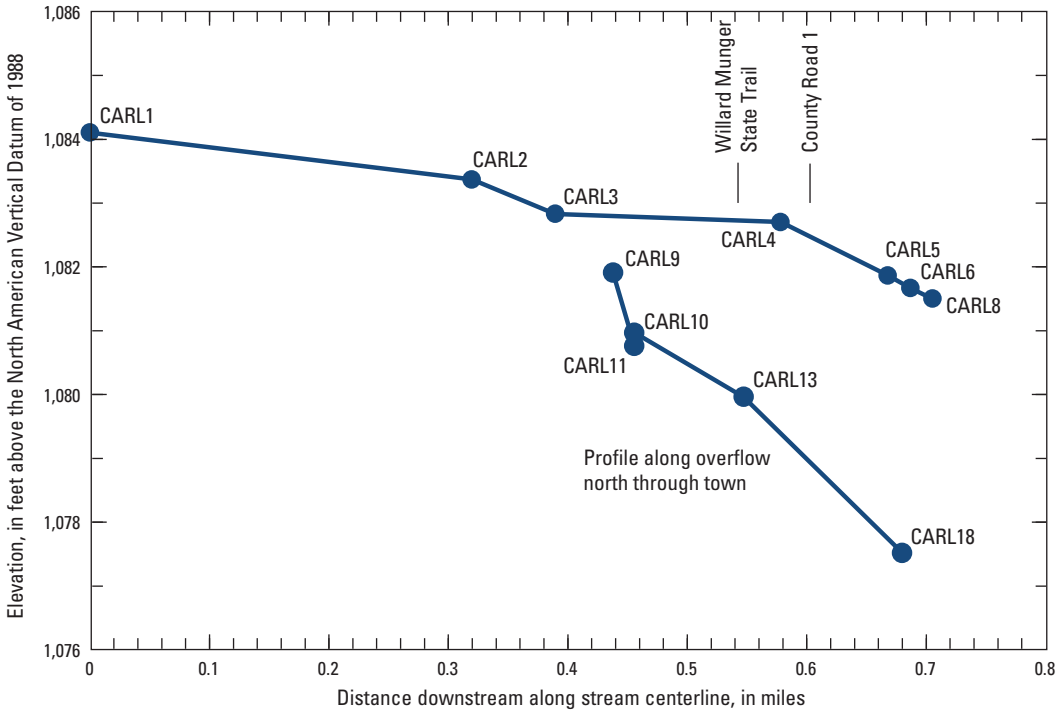


Figure 3–2. Flood-peak water-surface profile with selected high-water marks for Otter Creek at Carlton, Minnesota, for the flood of June 2012.

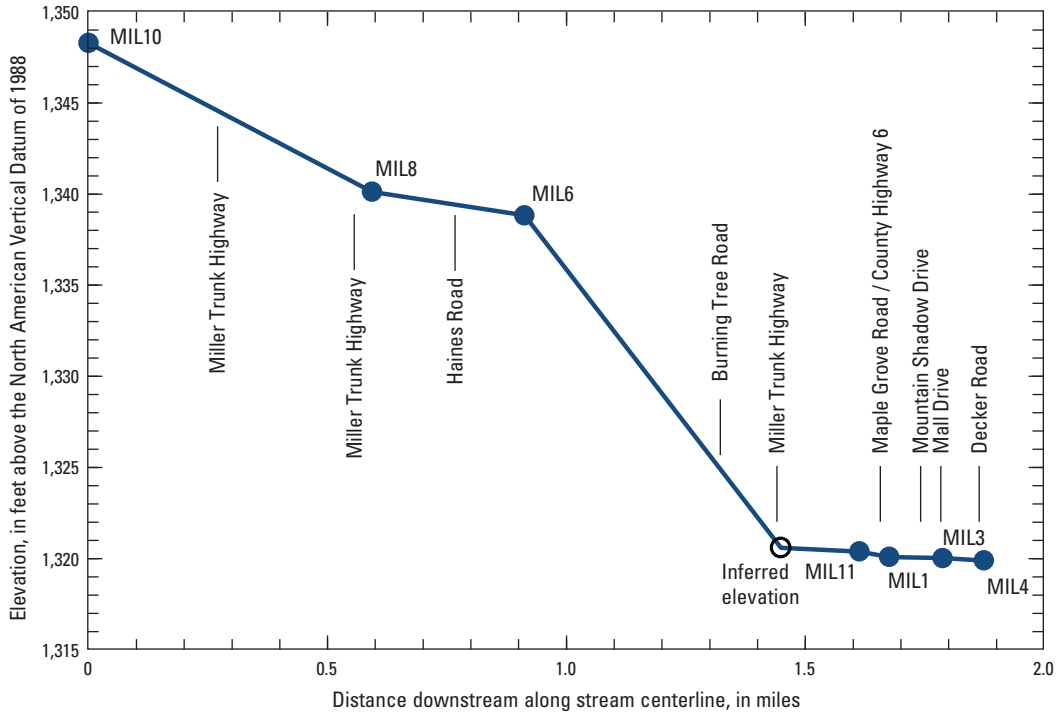


Figure 3–3. Flood-peak water-surface profile with selected high-water marks for Miller Creek at the Duluth Heights neighborhood, Duluth, Minnesota, for the flood of June 2012.

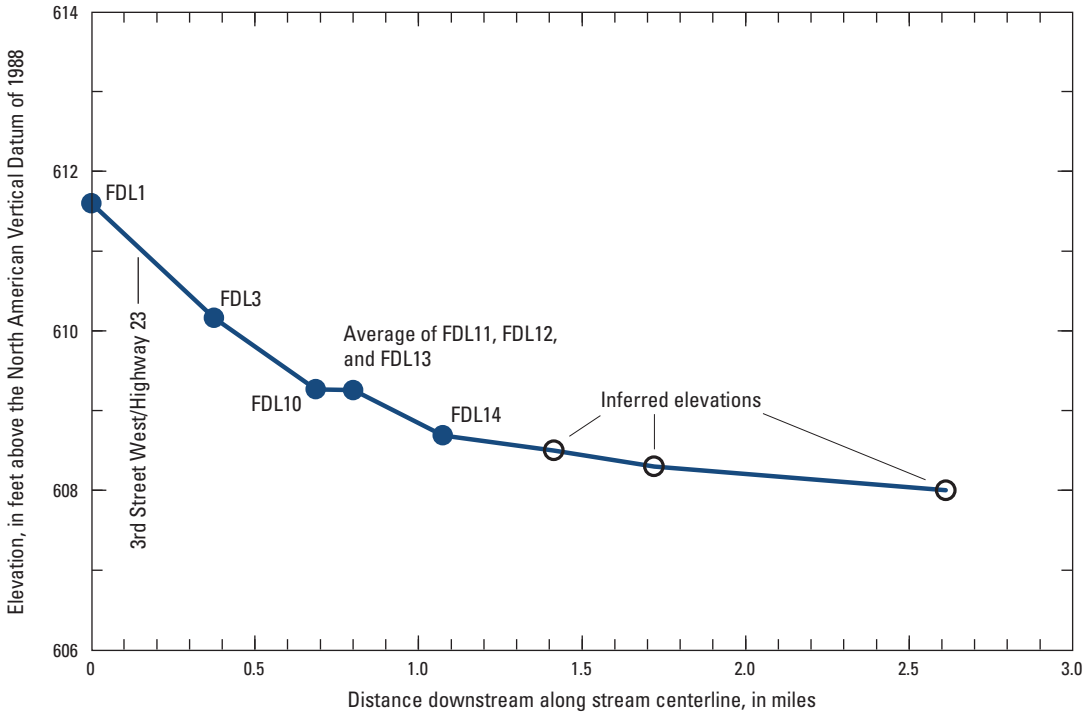


Figure 3–4. Flood-peak water-surface profile with selected high-water marks for the St. Louis River at the Fond du Lac neighborhood, Duluth, Minnesota, for the flood of June 2012.

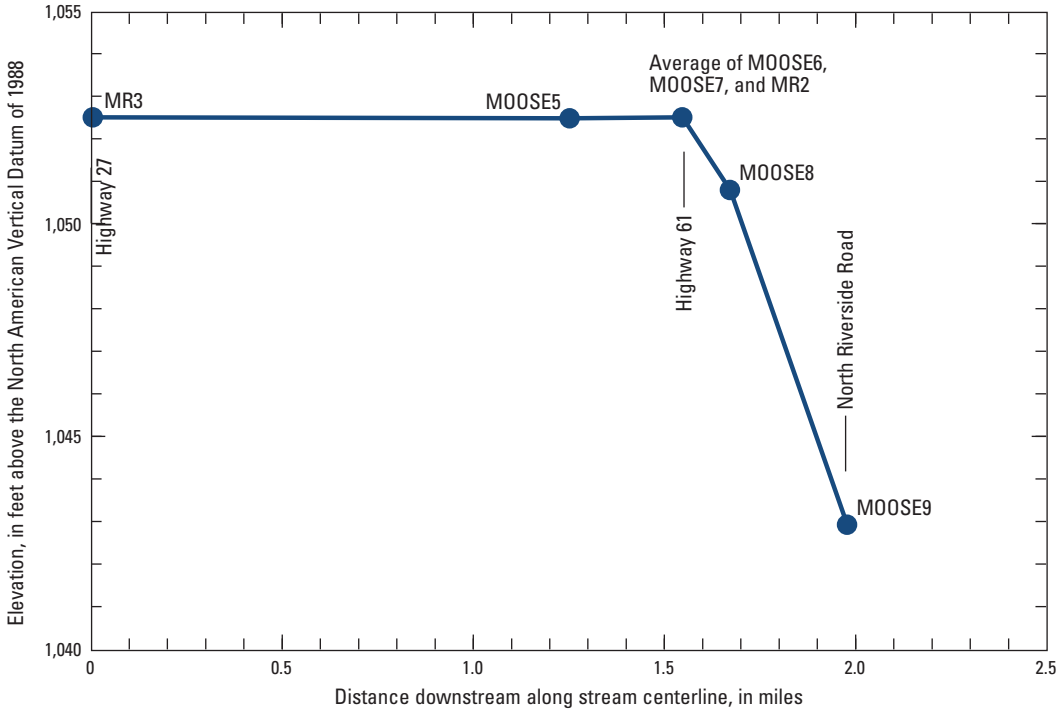


Figure 3–5. Flood-peak water-surface profile with selected high-water marks for the Moose Horn River and Moosehead Lake at Moose Lake, Minnesota, for the flood of June 2012.

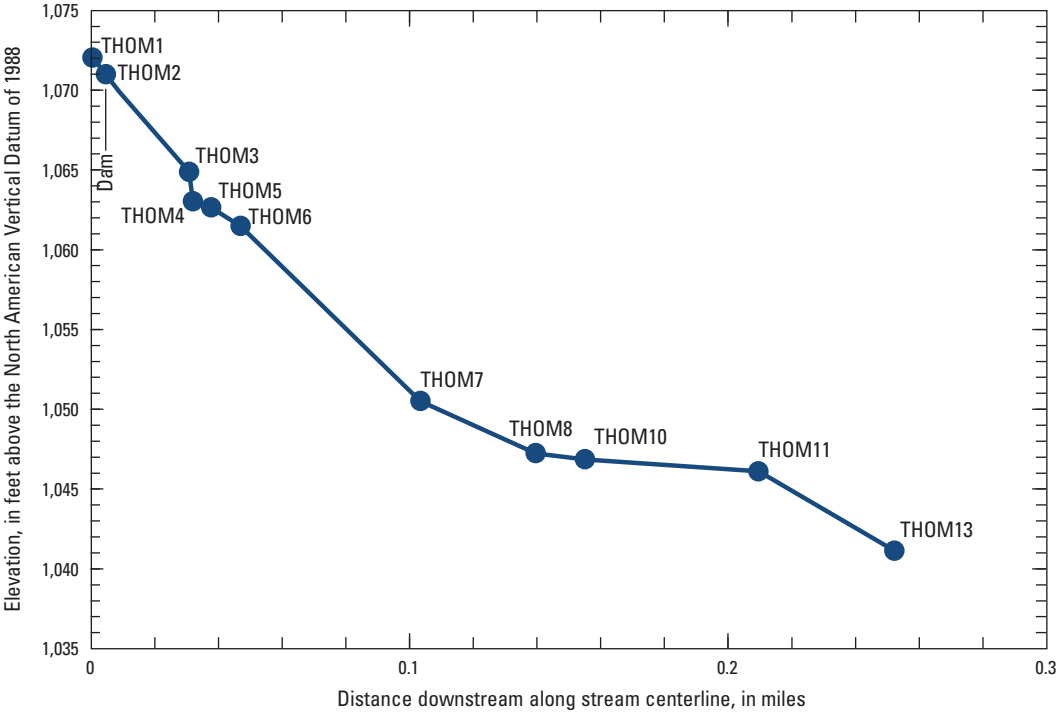


Figure 3–6. Flood-peak water-surface profile with selected high-water marks for the Thomson Reservoir outflow near the St. Louis River at Thomson, Minnesota, for the flood of June 2012.

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