Prepared in cooperation with the Federal Emergency Management Agency

Flood of June 2008 in Southern Wisconsin

Scientific Investigations Report 2008–5235

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

Cover: View of Baraboo River at Baraboo streamgage (05405000), June 12, 2008. Photograph by Tim Hanson, U.S. Geological Survey. Flood depth map is of downtown Reedsburg, Wisconsin. Map prepared by Marie Peppler, U.S. Geological Survey, June 2008. Map base from 2006 National Agricultural Imagery Program (U.S. Department of Agriculture, 2006).

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Conversion Factors and Datums

Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
meter (m)	3.281	foot (ft)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow or precipitation 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)

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88) unless noted as the North American Datum of 1927 (NAD 27).

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

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

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Flood of June 2008 in Southern Wisconsin

By Faith A. Fitzpatrick, Marie C. Peppler, John F. Walker, William J. Rose, Robert J. Waschbusch, and James L. Kennedy

Abstract

In June 2008, heavy rain caused severe flooding across southern Wisconsin. The floods were aggravated by saturated soils that persisted from unusually wet antecedent conditions from a combination of floods in August 2007, more than 100 inches of snow in winter 2007–08, and moist conditions in spring 2008. The flooding caused immediate evacuations and road closures and prolonged, extensive damages and losses associated with agriculture, businesses, housing, public health and human needs, and infrastructure and transportation.

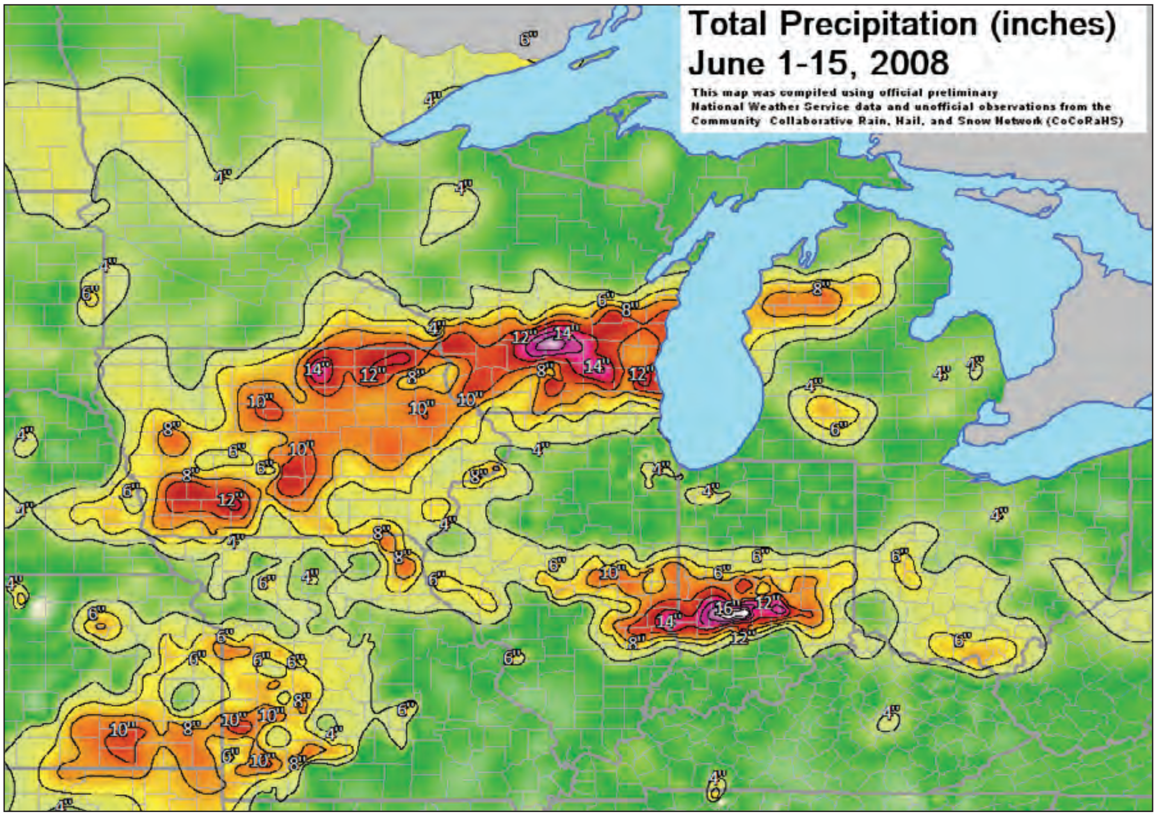
Record gage heights and streamflows occurred at 21 U.S. Geological Survey (USGS) streamgages across southern Wisconsin from June 7 to June 21. Peak-gage-height data, peak-streamflow data, and flood probabilities are tabulated for 32 USGS streamgages in southern Wisconsin. Peak-gage-height and peak-streamflow data also are tabulated for three ungaged locations.

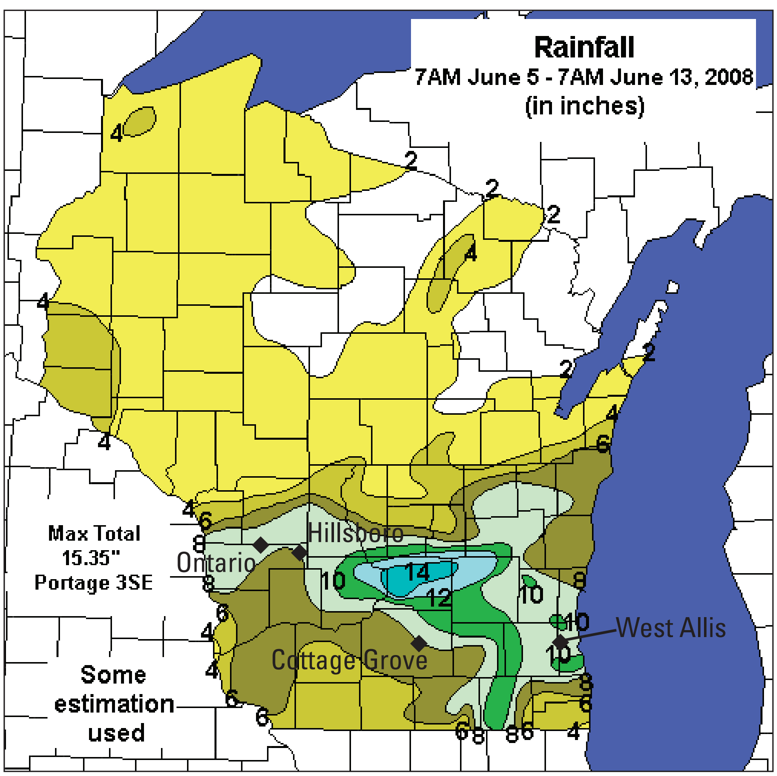
Extensive flooding along the Baraboo River, Kickapoo River, Crawfish River, and Rock River caused particularly severe damages in nine communities and their surrounding areas: Reedsburg, Rock Springs, La Farge, Gays Mills, Milford, Jefferson, Fort Atkinson, Janesville, and Beloit. Flood-peak inundation maps and water-surface profiles were generated for the nine communities in a geographic information system by combining flood high-water marks with available 1-10-meter resolution digital-elevation-model data. The high-water marks used in the maps were a combination of those surveyed during the June flood by communities, counties, and Federal agencies and hundreds of additional marks surveyed in August by the USGS. The flood maps and profiles outline the extent and depth of flooding through the communities and are being used in ongoing (as of November 2008) flood response and recovery efforts by local, county, State, and Federal agencies.

Introduction

Severe flooding in southern Wisconsin in early and mid-June 2008 was caused by repeated bouts of torrential rain, with 7-day rainfall totals in parts of south-central Wisconsin exceeding 12 in. (Midwestern Regional Climate Center, 2008; National Climatic Data Center, 2008) (fig. 1). The flooding was aggravated by unusually wet antecedent conditions. The heavy June rains were preceded by intensive rainfall of 10 to 12 in. on August 20, 2007, in southwest Wisconsin and more than 100 in. of snow in southern Wisconsin during winter 2007–08. As a result, soils already were saturated and streamflows elevated prior to the June 2008 flooding. The heaviest rainfall—as much as 2 in/h—fell on June 7 from multiple supercell thunderstorms that produced wall clouds, funnel clouds, and tornadoes (Wisconsin Recovery Task Force, 2008). Streams rose rapidly, and those that responded quickest began to peak on June 7. Continued rain on June 8 caused dam failures, road closures, mudslides, washouts, and evacuations. Portions of Interstates 94, 90/94, and 39 were closed for the first time ever due to high water. The Governor of Wisconsin requested a joint Federal/State preliminary damage assessment on June 10, 2008 (Wisconsin Recovery Task Force, 2008). Through the Major Disaster Declaration FEMA–1768–DR–WI, 31 counties in Wisconsin were declared disaster areas (fig. 2). Damages were extensive, including harm to critical facilities, utilities, and infrastructure (Wisconsin Recovery Task Force, 2008).

Given the severity of the June 2008 flooding, the U.S. Geological Survey (USGS), in cooperation with the Federal Emergency Management Agency (FEMA), conducted a study to document the meteorological and hydrological conditions leading to the flood; compile flood-peak gage heights, streamflows, and flood probabilities at USGS streamgages and estimated streamflows and flood probabilities at selected ungaged locations; construct flood profiles and peak-stage inundation maps; and summarize flood damages and impacts. Flood profiles and peak-stage inundation maps were constructed for nine communities along four major streams in southern Wisconsin: Reedsburg and Rock Springs along the Baraboo River; La Farge and Gays Mills along the Kickapoo River; Milford along the Crawfish River; and Jefferson, Fort Atkinson, Janesville, and Beloit along the Rock River (fig. 3; table 1).





EXPLANATION

◆ Cottage Grove — Precipitation station and name

Figure 1. Cumulative precipitation (top) in the Midwest for June 1 through June 15, 2008, and (bottom) in southern Wisconsin for June 5 through June 13, 2008. (images from National Weather Service, 2008, accessed October 31, 2008, at http://www.crh.noaa.gov/news/display_cmsstory.php?wfo=mkx&storyid=14030&source=0)

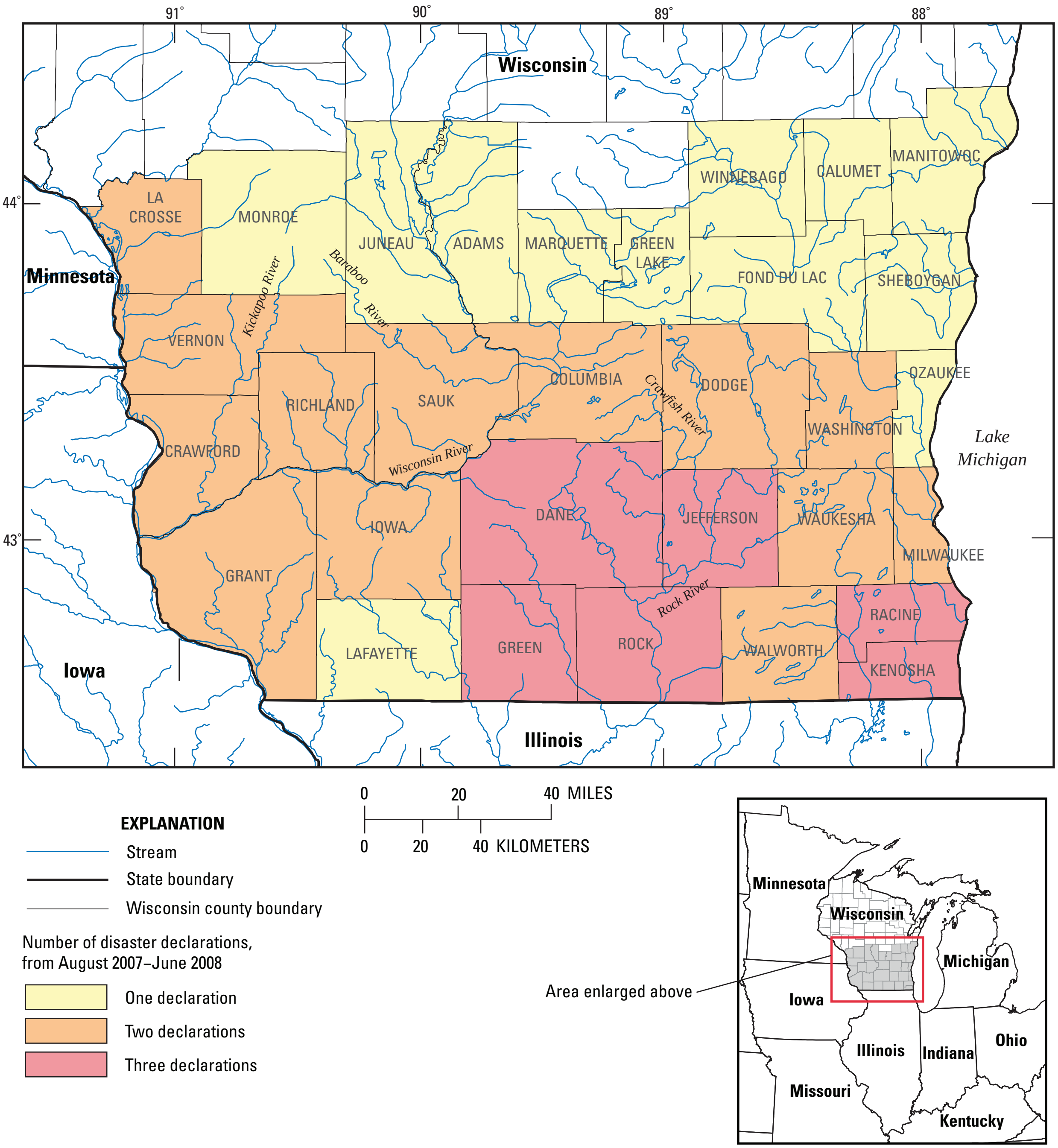


Figure 2. Thirty-one counties declared as disaster areas from August 2007 through June 2008 (from Wisconsin Recovery Task Force, 2008).

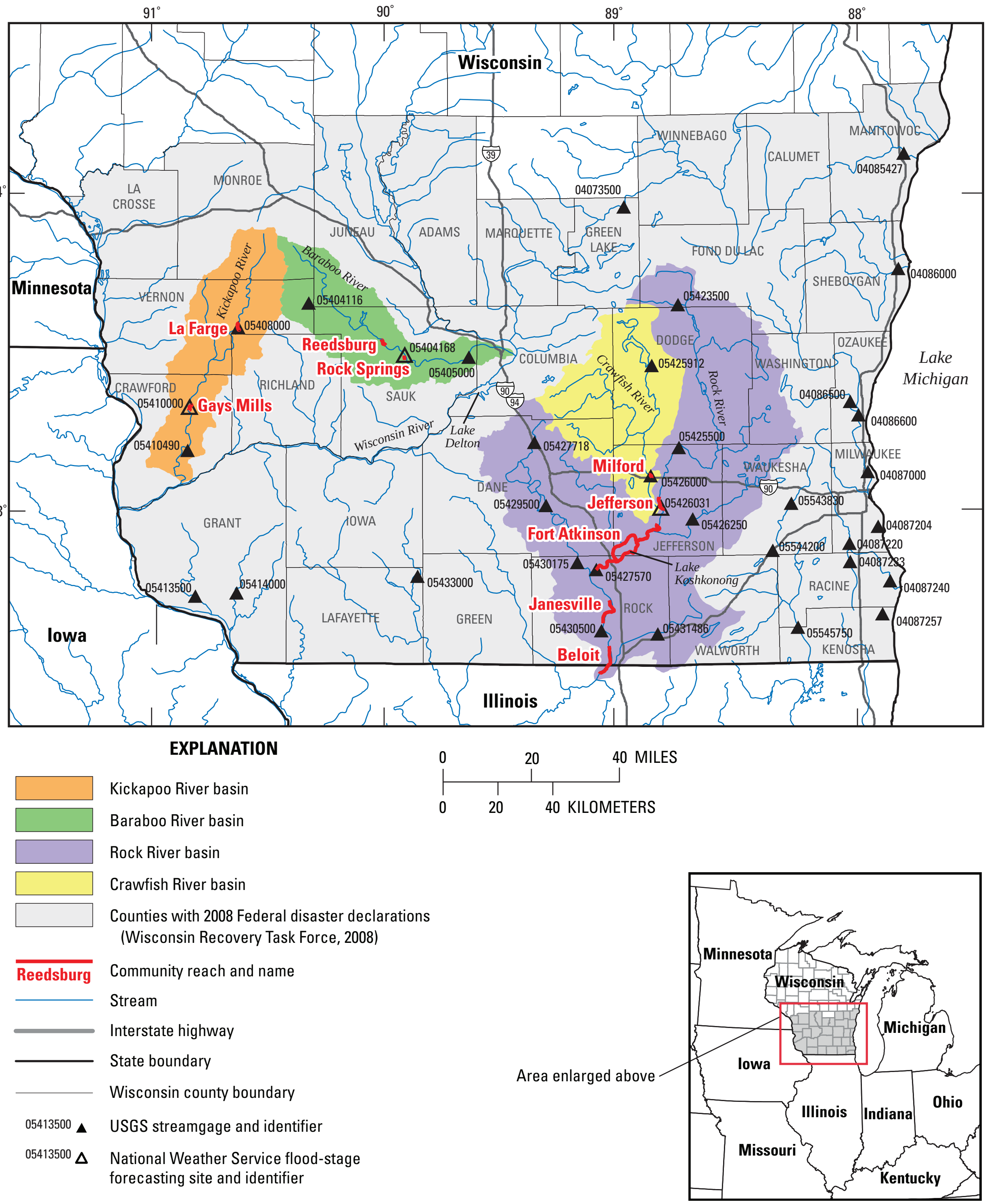


Figure 3. Study area in southern Wisconsin showing streamgages, river basins, and communities included in June 2008 flood study.

Table 1. Nine communities in southern Wisconsin along four major streams where high-water marks were flagged and flood-peak inundation maps and flood profiles were generated for the June 2008 flood.

[See figure 3 for location of communities. **Abbreviations:** USGS, U.S. Geological Survey; NWS, National Weather Service; DEM, digital-elevation model]

Community	Stream	Stream miles mapped	USGS streamgage or NWS site ID in or near reach	Population (U.S. Census Bureau, 2000)	Number of high-water marks		County	Resolution of available DEM data (meters)
					Located by USGS in August 2008	Included in final maps and tables		
Reedsburg	Baraboo River	2.5	None	7,827	37	[1]18	Sauk	3
Rock Springs	Baraboo River	1	05404168	425	49	12	Sauk	3
La Farge	Kickapoo River	1.5	05408000	775	30	15	Vernon	10
Gays Mills	Kickapoo River	2	05410000	625	33	27	Crawford	10
Milford	Crawfish River	1	05426000	1,055	25	8	Jefferson	1
Jefferson	Rock River	4	05426031	7,338	61	[2]19	Jefferson	1
Fort Atkinson	Rock River and Lake Koshkonong	15	05427470	11,621	81	[3]45	Jefferson/ Rock	3
Janesville	Rock River	6	05430500	59,498	31	[4]31	Rock	1
Beloit	Rock River	7	05430500	35,775	30	25	Rock	1

[1] Includes five high-water marks surveyed by the city of Reedsburg on June 10-11, 2008.

[2] Includes three high-water marks surveyed Jefferson County on June 18, 2008.

[3] Includes six high-water marks surveyed Jefferson County on June 19, 2008.

[4] Includes eight high-water marks surveyed by the city of Janesville on June 24, 2008.

Purpose and Scope

The purpose of this report is to provide timely hydrologic information pertaining to response and recovery from the June 2008 flood in southern Wisconsin. Hydrologic conditions leading up to the flood are summarized. The report contains recalculated flood-frequency statistics for 32 southern Wisconsin USGS streamgages that incorporate peaks from the June 2008 flood. High-water marks and flood-inundation maps and profiles are presented and described for nine communities along four major streams. Peak gage heights and streamflows were estimated by indirect methods for three of the nine communities without USGS streamgages. Flood damages also are summarized. Important findings related to the methods are briefly discussed.

Conditions Leading to the Flood

The June flooding in Wisconsin was caused by heavy rain falling on saturated soils at a time when streamflows already were much above normal. Wet conditions for the southwestern part of the state started on August 18, 2007, with intense, 10- to 12-in. rains that caused flooding and mudslides and resulted in disaster declarations for three southwestern counties. These rains followed a moderate to severe drought in the early summer months of 2007. In Madison, in south-central Wisconsin, an August 2007 rainfall total of 15.18 in. was the all-time highest rainfall total for any month since records had been kept starting in 1897.

Over the winter of 2007–08, heavy snowfall resulted in Federal disaster declarations for 10 counties in south-central and southeastern Wisconsin (Wisconsin Recovery Task Force, 2008). Snowfall in Madison set a record of 101.4 in. Precipitation for the following spring was well above normal (National Climatic Data Center, 2008). By late spring, streamflow and water tables were above normal across the region.

On the weekend of June 7 and 8, a stalled frontal boundary of an extremely moist air mass produced heavy rains that set a 48-hour rainfall record in Milwaukee of 7.18 in. and produced greater than 4 in. of rain in 24 hours in Milwaukee and Madison (National Weather Service, 2008). All-time daily rainfall records were set at four climate stations in southern Wisconsin (table 2). The 100-year 48-hour rainfall for southern Wisconsin is about 7 in. (Huff and Angel, 1992).

Table 2. Daily rainfall estimates for June 8 and 9, 2008, and rainfall probabilities for a 24-hour duration at National Weather Service (NWS) climate stations.

[Data from National Climatic Data Center (2008) and Huff and Angel (1992). See figure 1 for station locations. **Rainfall probability** is the probability or odds of having rainfall amounts equaled or exceeded for any given duration. For example, a probability of 0.01 means there is a 1 percent chance of that daily rainfall being equaled or exceeded. The probabilities of 0.01, 0.02, and 0.04 correspond to 100-, 50-, and 25-year rainfalls, respectively]

Station name	Date	Latitude	Longitude	NWS station identifier	Record for 24-hour duration (in.)			Period of record (years)	Rainfall probability for 24-hour duration (in.)		
					June 2008	Previous record	Date of previous record		0.04	0.02	0.01
Ontario, Wis.	06-08-2008	43.72	-90.60	476280	6.1	6.0	07-01-1978	34	5.3	6.0	7.0
Hillsboro, Wis.	06-08-2009	43.65	-90.33	473654	4.8	4.5	08-19-2007	61	5.2	6.0	7.0
West Allis, Wis.	06-08-2010	43.02	-88.00	479046	4.55	3.69	07-10-2006	58	4.9	5.5	6.5
Cottage Grove, Wis.	06-09-2011	43.08	-89.19	471840	4.47	4.38	09-15-1914	99	5.3	6.3	7.3

Another bout of intensive rain, funnel clouds, and flash floods occurred on June 12, resulting in a 7-day rainfall of 12–15 in. in south-central Wisconsin (National Weather Service, 2008). For southern Wisconsin, the 100-year 5-day rainfall for southern Wisconsin is 9–10 in. and the 100-year 10-day rainfall is 10–11 in. (Huff and Angel, 1992). Extensive flash flooding occurred in Sauk, Columbia, Jefferson, Waukesha, Milwaukee, and Racine Counties. At many locations, more than 70 percent of the rain fell on June 7, 8, and 12. By June 13, total precipitation exceeded 10 in. throughout south-central Wisconsin, with 12–16 in. concentrated in a corridor from northern Sauk County into northwest Dodge County (fig. 1). As of June 16, Milwaukee had 10.96 in. of rain for June, which is the record rainfall for any month. The Midwestern Regional Climate Center (2008) reported that precipitation amounts in southern Wisconsin were greater than 400 percent of normal values. For June 2008, new monthly records were set at several climate stations in southern Wisconsin (table 2).

Methods

Estimating the Magnitudes of Peak Streamflows

Peak streamflows documented in this study were determined at 32 USGS streamgages (fig. 3) by use of the rating curve (the relation between streamgage height and flow) for each station. Rating curves at streamgages are developed by relating gage height to streamflow for a range of flows. Streamflow data points used to develop a rating are determined most commonly by direct measurement at the streamgage (Rantz and others, 1982); or, if it is not possible to make a direct measurement, by indirect methods (Benson and Dalrymple, 1967). The rating curve is interpolated between measured streamflow data points and can be extrapolated beyond the highest streamflow data point; however, excessive extrapolation of the rating at high gage heights can result in large errors in streamflow (Rantz and others, 1982). Peak gage heights were obtained either from electronic data recorders or from surveyed high-water marks where recorders or stage sensors malfunctioned or were not available. The rating curve was used to compute peak streamflow from peak gage height. Direct streamflow measurements or streamflows determined by indirect methods served as recent data points for rating-curve verification and extrapolation. Flood-peak gage heights and streamflows were checked by USGS hydrologic technicians and determined to be correct as of October 2008.

Peak gage heights and streamflows were estimated for three ungaged sites through a variety of indirect methods, chosen on the basis of site conditions and available historical data. The three ungaged sites were the Baraboo River at Reedsburg, the Baraboo River at Rock Springs, and the Kickapoo River at Gays Mills. The Baraboo River at Rock Springs and Kickapoo River at Gays Mills are National Weather Service Peak Advanced Hydrologic Prediction Service automated and manual sites (http://www.crh.noaa.gov/ahps2/index.php?wfo=arx) for which there are gage-height data but no streamflow data (fig. 3).

Peak streamflow for the Baraboo River at Rock Springs was estimated through the use of the slope-area method (Dalrymple and Benson, 1967). In the slope-area method, streamflow is computed on the basis of a uniform-flow equation involving channel characteristics, water-surface profiles, and a roughness coefficient (Rantz and others, 1982). Computations were done with the USGS Slope Area Computation program (SAC) (Fulford, 1994) and surveyed channel geometry and high-water-mark data. An available HEC-RAS step-backwater hydraulic model for the Baraboo River was obtained from Robert Watson (National Flood Insurance Coordinator, Wisconsin Department of Natural Resources, written commun., 2008) and was used to determine the streamflow that yielded a profile that best matched the actual flood water-surface profile (Davidian, 1984).

For Rock Springs, the selected model-generated profile was within ±0.2 ft of high-water marks defining the actual flood profile. This provided an independent estimate of peak streamflow for comparison with the streamflow computed with the slope-area method.

In Reedsburg, no suitable stream reach was available to reliably employ the slope-area method, nor were there other suitable hydraulic features, such as a bridge contraction, that would allow employment of the contracted-opening method. An available HEC-RAS model was employed with various streamflows to generate water-surface profiles for comparison with the actual flood profile. The modeled streamflow that generated the profile that best matched the actual flood profile was selected for the peak-streamflow estimate. For Reedsburg, the peak flow was estimated to be within a range of discharge such that profiles determined by the low and high ends of the range were within 0.3 ft high water marks defining the actual peak flood flow.

For the Kickapoo River at Gays Mills, peak streamflow was estimated from rating extrapolation of USGS high-water marks and NWS flood-forecasting-station gage heights with historical stage-discharge measurements for the discontinued USGS streamgage in Gays Mills. The rating extrapolation was based on a log-based regression of historical floods greater than 5,000 ft^3/s in 1961, 1965, 1966, and 1978. The rating extrapolation also was done for the August 2007 flood based on NWS flood-forecasting-station gage heights (Michael A. Welvaert, National Weather Service, La Crosse, Wis., written commun., 2008). In addition, Robert Watson (National Flood Insurance Coordinator, Wisconsin Department of Natural Resources, Madison, Wis.) ran an available step-backwater model for the Kickapoo River reach near Gays Mills to estimate the peak streamflow. The estimate was the modeled discharge that generated a water-surface profile best matching the actual flood profile based on the USGS high-water-mark elevations. Gage heights were referenced to NAVD 88 datum based on surveys of the streamgage-reference marks during the high-water-mark surveying.

Calculating Flood Probabilities of Peak Streamflows

The flood probability for a particular streamflow is the probability or odds of that streamflow being equaled or exceeded in any given year. For example, a probability of 0.01 means there is a 1 percent chance of that flow magnitude being equaled or exceeded in any given year. Stated another way, the odds are 1 in 100 that flow will equal or exceed that magnitude in any given year. The traditional concept of recurrence interval is directly related to the flood probability. By definition, the recurrence interval corresponding to a particular flood probability is equal to one divided by the flood probability. For example, the flood probability of 0.01 corresponds to the 100-year flood.

Flood probabilities associated with the peak streamflows for streamgages and three ungaged locations were estimated to indicate the relative magnitude of the June 2008 flooding. Discharges for selected flood probabilities (0.20, 0.10, 0.04, 0.02, 0.01, 0.005, and 0.002) were estimated using the procedure recommended by the Interagency Advisory Committee on Water Data (1982), commonly called the Bulletin 17B procedure. Users of this procedure calculate flood probabilities by fitting systematic annual-peak-discharge data to a log-Pearson type III (LPIII) distribution. The population properties of the LPIII distribution are determined from the streamgage annual peak-flow data, which results in uncertainty in the estimates of the flood probabilities. The uncertainty is a function of the sample size, the accuracy of the streamgage record, and how well the LPIII distribution fits the underlying data. If two independent estimates of flood probability are available, a properly weighted estimate will have a lower uncertainty than either independent estimate (Interagency Advisory Committee on Water Data, 1982). As such, the method outlined in Bulletin 17B appendix 8 was used where possible to achieve lower uncertainty in the estimate. The weights were computed as the inverse of the respective variances of the two independent estimates.

In Wisconsin, the second independent estimate for each rural streamgage site was obtained by use of regional regression equations for rural conditions (Walker and others, 2003). For some streamgages, estimates of basin characteristics were determined by use of geographic information system (GIS) techniques, which differ slightly from the methods used to develop the regression equations (Walker and others, 2003); these cases are noted in table 3. In some cases, the regional regression equations were not applied because the streamgages were in urban areas or had regulated streamflows. For those sites without a valid second independent estimate for the flood probabilities, the Bulletin 17B estimates were used directly, with no weighting method applied.

Estimates of discharge for the selected flood probabilities can then be used to estimate the range of flood probabilities of a particular flood by means of two approaches. The upper and lower bounds for the range of probability are determined by comparing a particular flood peak (in this case, the peak from the 2008 flood) directly to estimated flood peaks for the selected probabilities. This method fails to consider the uncertainty of the estimates of flood peaks for the selected probabilities. An alternative approach is to determine the 95-percent confidence intervals for flood peaks corresponding to each of the selected probabilities and to compare the particular flood peak to these confidence intervals. If the flood peak falls within a particular confidence interval for a given probability, that probability is considered to be a likely estimate for that peak. In cases where the flood peak falls within the confidence interval for multiple probabilities, the estimated flood probability is reported as a range.

Collection of High-Water-Mark Data

High-water marks were identified and flagged by the USGS in nine communities in southern Wisconsin during August 4–28, 2008, approximately 2 months after floodwaters receded. High-water marks were set on both sides of each stream at spacing of approximately 500 to 1,000 ft, in accordance with standard USGS methods (Benson and Dalrymple, 1967). Commonly, stain lines on buildings, trees, or other structures were used. High-water marks were readily visible within the flooded areas despite the 2 months between flooding and high-water-mark identification (fig. 4). High-water marks were identified, mapped, and photographed, and associated information was recorded. 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. Data collected during marking were tabulated into a database. A subset of high-water marks previously surveyed by Jefferson County, the city of Reedsburg, city of Janesville, and the U.S. Army Corps of Engineers was used to supplement and verify USGS high-water marks and expand the spatial coverage for the inundation maps.

High-water marks were surveyed within a few days after marking with a combination of surveying techniques. Primarily, a Real Time Kinematic Global Positioning System (RTK-GPS) was used to survey each high-water mark. Quality-assurance procedures included setting up the RTK-GPS base station at a high location (roof of hospital, municipal building, on the valley side, and so forth) for maximum satellite reception and radio coverage and locating a minimum of two control points with multiple repeated readings (Vertical Second Order Class I; preferred). The preferred method of surveying a high-water mark was to simply set the GPS rover on the high-water mark and collect fixed-point data. If the high-water mark was too high above the ground or if tree cover or building interference would not allow a fixed solution, GPS data for an intermediate survey point were collected a short distance away. The difference in elevation between the intermediate survey point and the desired high-water mark was measured using a hand level or an auto-level and surveying rod. This difference was then used to adjust the surveyed intermediate elevation to the actual high-water-mark elevation during post-processing. The high-water marks were surveyed to an expected accuracy of 0.1 ft. The datum used was the North American Vertical Datum of 1988 (NAVD 88). When the community was being surveyed over multiple days with multiple setups, a procedure was used that required surveying overlapping points (at least one control point and a few high-water marks) from multiple survey setups so that elevations could be double-checked and the accuracy between the surveys established. If a community survey included deviations from the quality-assurance plan, an additional survey was done to verify the accuracy across and within individual surveys.

Inundation Mapping

Flood-peak inundation maps for the June 2008 flood were produced by use of GIS software and associated programs (Morlock and others, 2008). These maps show the maximum extent of floodwaters in and around each selected community. GIS layers of the high-water marks were generated from the survey data, overlain with the best digital-elevation-model (DEM) data available for each community, and superimposed on the corresponding National Agricultural Imagery Program 2006 air photo (U.S. Department of Agriculture, 2006) (table 1). The maps were checked by the USGS surveying and high-water-mark crews, and the high-water marks were compared spatially to check for mathematical or other errors. If a data point was still too high or too low when compared to neighboring points, the point in question was removed from the inundation mapping.

GIS Arc Macro Language (AML) programs were written to produce a plane representing the flood-peak water surface, which was fit through the high-water marks and sloped in the direction of water flow (Leslie Arihood, USGS Indiana Water Science Center, written commun., August 2008). Elevations between high-water marks are proportional interpolations of the high-water-mark data. A TIN (triangular irregular network) surface was fit through the data points, forming the estimated flood surface. A flood-depth map was made by subtracting the DEM of the land surface from the flood-peak water surface. The flood-peak inundated area TIN models were exported in a GIS file format (shapefiles) that delineates flood-peak extent.

After the elevation of the flood peak was determined and checked, flood-peak elevations from five streamgages in the communities were compared to surveyed high-water marks. The high-water-mark crews located a high-water mark directly on the streamgage house or nearby. The survey crews surveyed the reference marks at the streamgages along with the high-water marks to allow the arbitrary gage height to be shifted to match the survey data. This method served as an independent check of the flood-peak elevations in those communities.

Draft maps of the modeled flood-peak extent were sent to a contact in each community as an outside check of the model. Typically, the city engineer or public works director was present during the flood and was able to verify the flood extent through personal experience, photographs, air photography, and coincident high-water-mark surveying. The flood-extent maps were checked and corrected as needed by each community. Corrections from the local community were minimal or none for all seven communities with high resolution DEM data of 3 m or less (table 1). If there were flood-extent corrections made by these communities, the corrections were likely due to local temporary flood-protection efforts, such as sandbagging. Comparison of the modeled flood-extent maps with aerial photographs taken around the peak of the flood were an additional way to confirm the accuracy of the modeled inundated areas.

A. Reedsburg high-water mark 2, mudline on electrical box of sewage pump station, corroborated with city of Reedsburg mark surveyed in June during high water.

B. Jefferson high-water mark 41, corroborated with water-stain/mud lines on nearby step, light pole, and previously surveyed high-water marks by Jefferson County during the June flood.

Figure 4. Example photographs of high-water marks in August 2008.

Flood-Peak Profiles

Standard USGS methods were used to measure flood-peak water-surface profiles from the high-water mark elevations and locations. Flood profiles were produced by plotting high-water-mark elevations by mile of stream as measured on the centerline for the flooded area from the base of the reach. The water surface between high-water marks was estimated by linear interpolation. Additional location information was added to the plot, such as the locations of street crossings or dams.

Flood of June 2008 in Southern Wisconsin

Estimated Magnitudes and Flood Probabilities of Peak Streamflows

Peak-gage-height data, peak-streamflow data, and estimated flood probabilities from the June flood for 32 USGS streamgages and 3 ungaged locations are presented in tables 3 and 4. The data listed in table 3 have not received final checks as of the date of writing (December 2008) and are considered provisional until published in the USGS "Water-Resources Data for the United States" annual report for water year 2008.

Table 5 lists the correspondence between flood probability and recurrence intervals for commonly used flood probabilities. New gage-height or streamflow records were set at 21 USGS streamgages. Flood probabilities at the streamgages with record gage-height or streamflow ranged from 0.002 to 0.04 (range based on 95-percent confidence intervals). Five streamgages had estimated flood probability ranges of 0.005 or less based on the 95-percent confidence intervals (table 3). The Baraboo River peaked at 10 ft above flood stage (National Weather Service, 2008). Some streams rose and fell rapidly beginning on June 7 or soon after (table 3, fig. 5). Large streams took longer to peak; the Rock River at Afton did not peak until June 21, and flooding continued into July (table 3, fig. 5).

The June 2008 flood took on different characteristics in each of the nine severely damaged communities included in this study. At Reedsburg and Rock Springs, flows of the Baraboo River peaked at approximately 11,500 to 12,900 ft^3/s in the early hours of June 10 after especially heavy rainfall fell on the watershed upstream from these communities (table 4). Farther downstream and to the east, the Baraboo River at Baraboo peaked 3 days later from additional thunderstorms that hit the eastern part of the watershed harder than the western part upstream from Reedsburg (figs. 1 and 5). The flooding on the Baraboo River likely had flood probabilities of 0.002 or less (table 3). Flooding on the Baraboo River was responsible for unprecedented closures of Interstates 90-94 and 39 north of Madison.

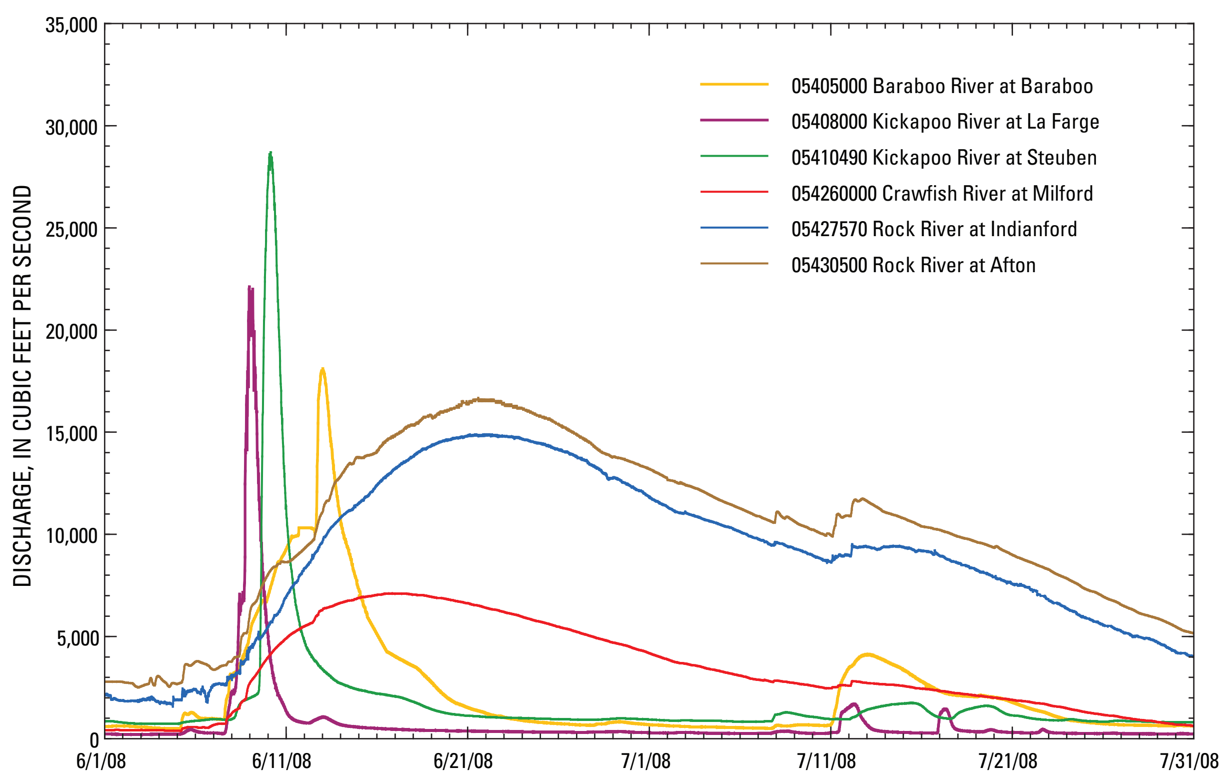


Figure 5. Hydrographs showing selected USGS streamgages in southern Wisconsin for June–July 2008. Locations of streamgages shown on figure 3.

Table 3. Flood-peak gage heights, peak streamflows, and estimated flood probabilities during the June 2008 flood at selected U.S. Geological Survey streamgages in southern Wisconsin.

[The data shown are considered provisional as of the date of publication. Final data will be published in the USGS "Water Resources Data for the United States" annual report for water year 2008. See figure 3 for streamgage locations. Peak of record shown in **bold**. **Estimated flood probability range based on estimates:** The flood probability for a particular streamflow is the probability or odds of that streamflow being equaled or exceeded in any given year. For example, a probability of 0.01 means there is a 1 percent chance of that flow magnitude being equaled or exceeded in any given year. Stated another way, the odds are 1 in 100 flow will equal or exceeded that magnitude in any given year. The traditional concept of recurrence interval is directly related to the flood probability. By definition, the recurrence interval corresponding to a particular flood probability is equal to one divided by the flood probability. For example, the flood probability of 0.01 corresponds to the 100-year flood. Based on direct comparison of flood-peak discharge to the discharge estimates for various flood probabilities (traditional approach). **Estimated flood probability range based on 95-percent confidence intervals:** Based on comparison of flood-peak discharge to the lower and upper bounds of the 95-percent confidence limits for discharge estimates for various flood probabilities (alternative approach). **Abbreviations:** mi^2, square miles; ft^3/s, cubic feet per second, yr, year; >, greater than; < less than; n/a not applicable or not available; ND, not determined; e, estimated; P, present; LP3, procedure for calculating flood probabilities by fitting systematic annual-peak-discharge data to a log-Pearson type III distribution (Interagency Advisory Committee on Water Data, 1982). WIE, flood probabilities calculated using weighting of independent estimates procedure (Interagency Advisory Committee on Water Data, 1982, appendix 8); GIS, used GIS-based basin characteristics for regional regression equations used in WIE procedure; Regional regression equations from Walker and Krug (2003)]

				Maximum prior to current flood			Maximum for June 2008 flood							
												Estimated flood-probability range (years)[1]		
USGS station No.	Stream and place of determination	Drainage area (mi^2)	Gage period of record (water years)	Date	Gage height (feet)	Discharge (ft^3/s)	Date	Time	Gage height (feet)	Discharge (ft^3/s)	Period of record outlier based on LP3 procedure	Based on estimate[2]	Based on 95-percent confidence intervals[3]	Frequency calculation best-fit method
04073500	Fox River at Berlin	1,340	1898-P	03-17-1946	15.50	6,900	06-22-2008	18:30	[4]16.08	6,080		0.04–0.1	0.04	WIE
04085427	Manitowoc River at Manitowoc	526	1972-96, 1997-P	03-31-1979	13.24	8,280	06-13-2008	05:30	12.04	6,100		0.04–0.1	0.02–0.1	WIE-GIS
04086000	Sheboygan River at Sheboygan	418	1916-24, 1951-P	08-06-1998	12.02	7,820	06-09-2008	08:25	11.08	6,810		0.04–0.1	0.04–0.1	WIE
04086500	Cedar Creek near Cedarburg	120	1930-70, 1974-81, 1983-87, 1991-P	03-30-1960	12.25	3,600	06-14-2008	09:00	10.59	1,880		0.1–0.2	0.2	WIE
04086600	Milwaukee River near Cedarburg	607	1981-P	05-23-2004	13.11	5,720	**06-13-2008**	**18:45**	**13.98**	**6,980**		0.01–0.02	0.005–0.04	WIE-GIS
04087000	Milwaukee River at Milwaukee	696	1914-P	06-21-1997	10.00	16,500	06-07-2008	22:00	8.07	10,400		0.04–0.1	0.04	WIE
04087204	Oak Creek at South Milwaukee	25.0	1964-P	08-06-1986	9.88	1,140	**06-07-2008**	**20:00**	**11.56**	**2,370**	**yes**	<0.002	0.002–0.005	WIE
04087220	Root River near Franklin	49.2	1964-P	03-30-1960	9.57	5,130	**06-08-2008**	**14:00**	**11.00**	**5,350**		0.01–0.02	0.005–0.02	LP3–49% URBAN
04087233	Root River Canal near Franklin	57.0	1964-P	03-04-1974	9.88	1,440	**06-09-2008**	**04:30**	**12.13**	**1,560**		0.02–0.04	0.01–0.04	WIE
04087240	Root River at Racine	190	1963-P	03-05-1974	8.54	4,500	**06-09-2008**	**10:30**	**11.29**	**8,050**	**yes**	<0.002	0.002–0.005	WIE
04087257	Pike River near Racine	38.5	1972-P	08-20-2007	8.24	1,720	**06-08-2008**	**01:30**	**8.97**	**1,960**		0.01–0.02	0.002–0.04	LP3–21% URBAN
05404116	West Branch Baraboo River at Hillsboro	39.1	1989-P	06-29-1990	15.60	4,010	**06-08-2008**	**21:00**	**16.12**	**5,260**	**yes**	0.01–0.02	0.002–0.04	WIE-GIS
05405000	Baraboo River near Baraboo	609	1914-22, 1943-P	03-26-1917	17.50	7,900	**06-13-2008**	**00:30**	**27.48**	**18,100**	**yes**	<0.002	0	WIE
05408000	Kickapoo River at La Farge	266	1939-P	07-01-1978	14.92	14,300	**06-08-2008**	**23:15**	**15.78**	**22,100**	**yes**	0.002–0.005	0.002–0.01	WIE

Table 3. Flood-peak gage heights, peak streamflows, and estimated flood probabilities during the June 2008 flood at selected U.S. Geological Survey streamgages in southern Wisconsin.—Continued

USGS station No.	Stream and place of determination	Drainage area (mi^2)	Gage period of record (water years)	Maximum prior to current flood: Date	Maximum prior to current flood: Gage height (feet)	Maximum prior to current flood: Discharge (ft^3/s)	Maximum for June 2008 flood: Date	Time	Gage height (feet)	Discharge (ft^3/s)	Period of record outlier based on LP3 procedure	Estimated flood-probability range (years)[1]: Based on estimate[2]	Estimated flood-probability range (years)[1]: Based on 95-percent confidence intervals[3]	Frequency calculation best-fit method
05410490	Kickapoo River at Steuben	687	1933-P	07-03-1978	14.81	16,500	**06-10-2008**	**03:15**	**19.16**	**28,700**	yes	0.002–0.005	0.002–0.01	WIE
05413500	Grant River at Burton	269	1935-P	07-16-1950	24.82	25,000	06-13-2008	02:45	23.31	13,000		0.1–0.2	0.1	WIE
05414000	Platte River near Rockville	142	1935-P	07-16-1950	17.26	43,500	06-12-2008	19:30	e14.17	e15,200		0.02–0.04	0.01–0.04	WIE
05423500	South Branch Rock River at Waupun	63.6	1949-69, 1987-P	04-03-1959	7.97	1,500	**06-13-2008**	**08:00**	**10.09**	**2,350**		0.005–0.01	0.002–0.02	WIE
05425500	Rock River at Watertown	969	1932-70, 1977-P	03-31-1979	6.19	5,080	**06-13-2008**	**08:30**	**7.81**	**7,600**		0.002–0.005	0.002–0.01	WIE
05425912	Beaver Dam River at Beaver Dam	157	1985-P	06-14-2004	10.68	1,140	**06-16-2008**	**14:45**	[5]**845.53**	**1,700**	yes	0.005–0.01	0.002–0.02	LP3-REGULATED
05426000	Crawfish River at Milford	762	1932-P	04-06-1959	11.15	6,140	**06-16-2008**	**15:45**	**13.35**	**7,190**		0.002–0.005	0.002–0.01	WIE
05426250	Bark River near Rome	122	1980-P	04-20-1993	2.56	476	**06-09-2008**	**01:00**	**4.59**	**1,370**	yes	<0.002	0.002–0.005	WIE-GIS
05427570	Rock River at Indianford	2,630	1975-P	04-05-1979	16.23	11,900	**06-21-2008**	**03:00**	**18.33**	**14,900**		0.01–0.02	0.002–0.04	WIE
05427718	Yahara River at Windsor	73.6	1976-81, 1990-P	07-06-1993	6.58	2,050	**06-09-2008**	**01:30**	**6.97**	**3,290**	yes	0.01–0.02	0.002–0.04	WIE-GIS
05429500	Yahara River at McFarland	327	1931-P	04-10-1959	5.82	867	**06-14-2008**	**00:15**	**7.17**	**976**		0.002–0.005	0.005–0.01	WIE-GIS
05430175	Yahara River near Fulton	518	1977-P	06-18-1996	11.16	3,230	06-14-2008	00:45	9.87	2,600		0.1–0.2	0.1–0.2	WIE-GIS
05430500	Rock River at Afton	3,340	1914-P	03-23-1929	11.81	13,000	**06-21-2008**	**14:00**	**13.51**	**16,700**		0.002–0.005	0.002–0.01	WIE
05431486	Turtle Creek Carvers Rock Road near Clinton	199	1940-P	04-21-1973	12.85	16,500	06-13-2008[6]	17:15	8.54	2,010		>0.2	>0.2	WIE-GIS
05433000	East Br. Pecatonica River near Blanchardville	221	1939-86, 1988-P	02-28-1948	15.74	11,700	06-09-2008	23:15	15.15	2,540		>0.2	>0.2	WIE
05543830	Fox River at Waukesha	126	1963-P	04-01-1960	8.00	2,500	**06-09-2008**	**17:45**	**8.85**	2,440		0.01–0.02	0.005–0.04	WIE-GIS
05544200	Mukwonago river at Mukwonago	74.1	1973-P	08-22-2007	3.96	317	**06-13-2008**	**04:45**	**4.95**	**364**		0.005–0.01	0.002–0.04	WIE-GIS
05545750	Fox River near New Munster	811	1940-P	03-31-1960	9.25	7,520	06-15-2008	17:45	[4]15.18	5,960		0.02–0.04	0.02–0.04	WIE-GIS

[1]The flood probability for a particular streamflow is the probability or odds of that streamflow being equaled or exceeded in any given year. For example, a probability of 0.01 means there is a 1 percent chance of that flow magnitude being equaled or exceeded in any given year. Stated another way, the odds are 1 in 100 flow will equal or exceed that magnitude in any given year. The traditional concept of recurrence interval is directly related to the flood probability. By definition, the recurrence interval corresponding to a particular flood probability is equal to one divided by the flood probability. For example, the flood probability of 0.01 corresponds to the 100-year flood.

[2]Based on direct comparison of flood-peak discharge to the discharge estimates for various flood probabilities (traditional approach).

[3]Based on comparison of flood-peak discharge to the lower and upper bounds of the 95% confidence limits for discharge estimates for various flood probabilities (alternative approach).

[4]Gage datum changes or stage shifts over period of record.

[5]Gage datum changes or stage shifts over period of record. Gage vertical datum is referenced to the North American Datum of 1927.

[6]Peak for the year happened on July 12, 2008, at 15:45, GH = 10.07 and Q = 3,650.

Table 4. Estimated peak gage heights, streamflows, and flood probabilities for selected locations in southern Wisconsin, June 2008 flood.

[Estimated flood probabilities based on regional regression equations from Walker and Krug (2003). **Peak flow for given flood probability**: The flood probability for a particular streamflow is the probability or odds of that streamflow being equaled or exceeded in any given year. For example, a probability of 0.01 means there is a 1 percent chance of that flow magnitude being equaled or exceeded in any given year. Stated another way, the odds are 1 in 100 flow will equal or exceeded that magnitude in any given year. The traditional concept of recurrence interval is directly related to the flood probability. By definition, the recurrence interval corresponding to a particular flood probability is equal to one divided by the flood probability. For example, the flood probability of 0.01 corresponds to the 100-year flood. **Abbreviations:** USGS, U.S. Geological Survey; mi^2, square miles; ft^3/s, cubic feet per second; YR, year; <, less than; >, greater than; HWM, high-water mark; NWS National Weather Service; na, not available]

USGS identification number	Stream and community	Type of site	County	Drainage area at site (mi^2)	Peak flow for given flood probability (ft^3/s)				Estimated peak flow during June 2008 flood			
					0.1	0.04	0.02	0.01	Date	Peak gage height (feet)	Estimated peak flow (ft^3/s)	Method
None	Baraboo River at Reedsburg	No gage data available	Sauk	391	na	na	na	na	06/10/2008	na	11,500–12,500	Estimated by use of USGS high-water-mark data and available step-backwater hydraulic model extended upstream from Rock Springs.
05404320	Baraboo River at Rock Springs	NWS flood-stage forecasting site	Sauk	484	na	na	na	na	06/10/2008	28.7	12,900	Estimated by use of available NWS gage height and USGS high-water-mark data, slope-area method, and an available step-backwater hydraulic model.
05410000	Kickapoo River at Gays Mills	NWS flood-stage forecasting site, discontinued USGS streamgage	Crawford	616.6	6,740	8,910	10,600	12,500	06/09/2008	20.4	19,200–22,000	Estimated by use of gage height at NWS flood-stage forecasting site, rating extrapolation for discontinued streamgage, and available step-backwater hydraulic model.

Table 5. Association between flood probability and recurrence interval for selected probabilities.

Flood probability	Recurrence interval (years)
0.2	5
0.1	10
0.04	25
0.02	50
0.01	100
0.005	200
0.002	500

The Kickapoo River at the communities of La Farge, Gays Mills, and Steuben rose and fell rapidly from June 8 to June 12 following the weekend rains on June 7–8 (fig. 5; tables 3 and 4). Peak streamflows at La Farge, Gays Mills, and Steuben had flood probabilities of 0.002 to 0.01 (tables 3, 4, and 5). Peak streamflow for Gays Mills was estimated to range from 19,200 ft^3/s (rating extrapolation) to 22,000 ft^3/s (step-backwater model, Robert Watson, National Wisconsin Department of Natural Resources, written commun., 2008).

Peak streamflow estimates for the Kickapoo River at Gays Mills seem low compared with peak streamflows for La Farge (upstream 22,100 ft^3/s) and Steuben (downstream, 28,700 ft^3/s); however, comparison of historical peak streamflows of the Kickapoo River from the three streamgages indicate that the peak streamflows can vary from what would be expected based on basin size. Possibly storm tracks and flood-plain storage, among other unknown factors, affect peak streamflow relations among the three streamgages. Gage heights for the June 2008 flood peak in La Farge, Gays Mills, and Steuben were 0.9, 1.9, and 4.4 ft higher than the gage heights for the July 1978 flood, respectively (fig. 6, tables 3 and 4; Hughes and others, 1981). For Gays Mills, the June 2008 gage height was approximately 0.3 ft higher than the August 2007 flood-peak gage height (fig. 6).

Farther east, the Crawfish River at Milford rose more slowly than the Kickapoo and Baraboo Rivers and peaked on June 16 after the second set of thunderstorms on June 12 (fig. 5, table 3). The low-lying gentle topography and numerous wetlands in the Crawfish River watershed contributed to the long duration of the flood, which lingered into the latter part of June. Peak streamflow for the Crawfish River likely had a flood probability less than 0.01 (table 3).

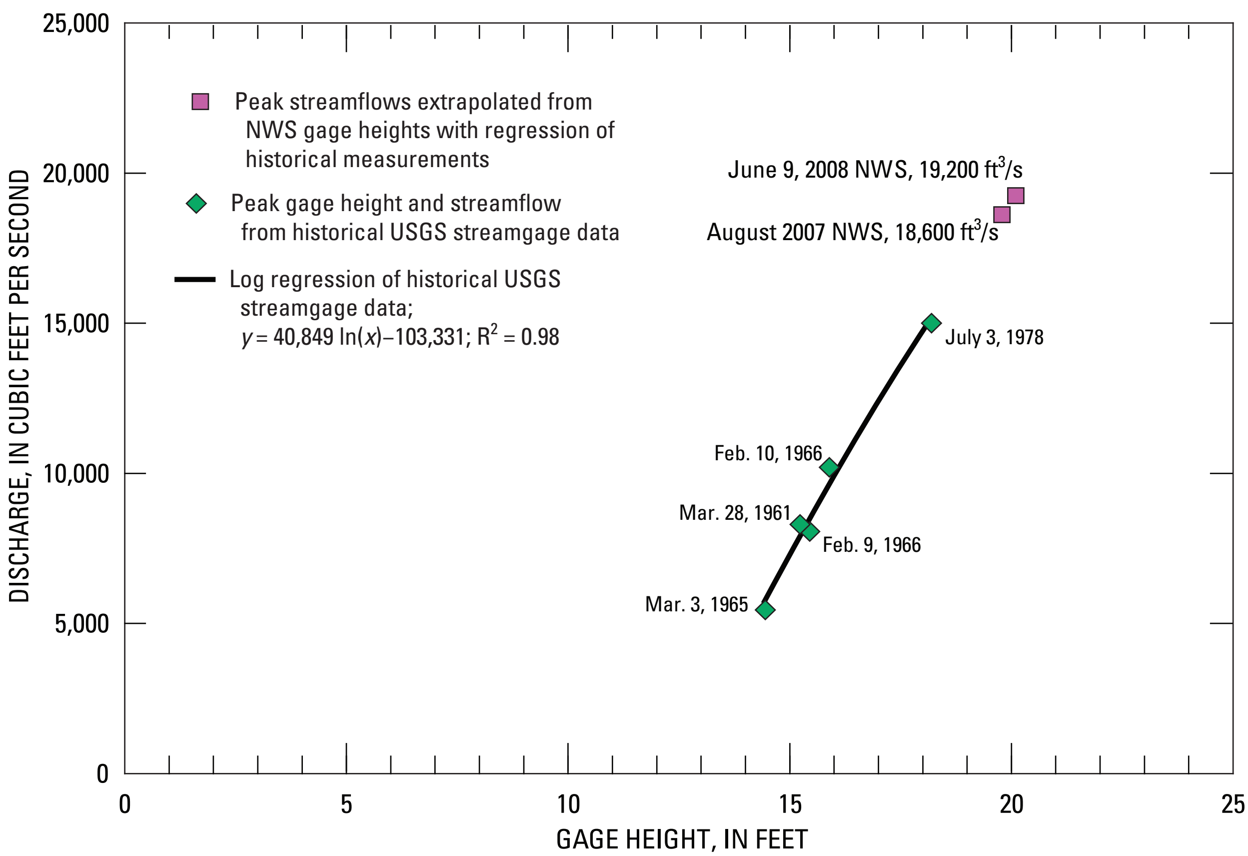


Figure 6. Computation of flood peaks at Gays Mills based on rating curve developed from stage-discharge relations of historical floods. (NWS, National Weather Service; USGS, U.S. Geological Survey; HWM, High-water mark; ft^3/s, cubic feet per second.)

The communities of Jefferson, Fort Atkinson, Janesville, and Beloit along the Rock River also experienced prolonged flooding (fig. 5), and the Rock River did not peak until June 21 at Indianford and Afton (table 3). Estimates for flood probabilities for the flooding along the Rock River range widely, from 0.002 to 0.04 (table 3). The extended time for the Rock and Crawfish Rivers flooding resulted in the unprecedented closure of westbound Interstate 94 for June 13–19 between Milwaukee and Madison (Channel 3000, 2008).

Flood-Peak Inundation Maps and Profiles

Flood-peak inundation maps and profiles for nine communities are provided in appendixes 1 through 9. The appendixes contain descriptive tables of a subset of high-water marks used in the inundation mapping (appendixes 1*A* through 9*A*). Two flood-peak inundation maps were generated for each community: one shows the modeled flood extent and high-water-mark locations and elevations on a background of 2006 National Agricultural Imagery Program (U.S. Department of Agriculture, 2006) aerial photographs (appendixes 1*B* through 9*B*), and the second shows shaded flood depths (appendixes 1*C* through 9*C*). Flood-peak profiles show how the modeled flood-peak inundation surface and slope vary along the modeled stream reach through each community (appendixes 1*D* through 9*D*). Highlights from each community's mapping process and accuracy are described below, including specific checks in the high-water marks or mapping.

Baraboo River at Reedsburg

The Baraboo River flows for approximately 2.5 mi southeast through the community of Reedsburg in Sauk County (appendix 1). The accuracy of the USGS high-water marks was corroborated with nearby high-water marks surveyed during the flood by the city of Reedsburg. Aerial photographs taken around the peak of the flood were an additional way to confirm the accuracy of the modeled inundated area in Reedsburg (fig. 7). The flooding along North Webb Avenue in Reedsburg is an example of how the flood-extent map closely reflects the actual conditions in that some of the houses along North Webb Avenue, the community pool, and the intersection with Main Street were not flooded. Several blocks were flooded upstream and downstream from State Highway 33 (Main Street), which runs through the center of town. The houses southwest of town along Granite Avenue were especially devastated from high-velocity flows constricted at the railroad bridge. The modeled inundated area of flooding in Reedsburg (appendixes 1*B* and 1*C*) is especially detailed because of the 3-m resolution of the Sauk County DEM data. Reedsburg flood-peak inundation maps were verified through a series of aerial photographs taken on June 10, and no corrections were necessary. There is no USGS streamgage in Reedsburg, but peak streamflow for the Baraboo River was estimated to be 11,500–12,500 ft^3/s (table 4).

Baraboo River at Rock Springs

The Baraboo River flows south along a 1-mi-long narrow rock gorge that widens at the community of Rock Springs in Sauk County (appendix 2). High-water marks were compared to peak gage height recorded at the NWS flood forecasting site at the bridge crossing in downtown Rock Springs as part of the indirect streamflow estimate. Peak streamflow for the Baraboo River at Rock Springs was estimated to be 12,900 ft^3/s (table 4). The modeled inundated area of flooding in Rock Springs (appendixes 2*B* and 2*C*) is especially detailed because of the 3-m resolution of the Sauk County DEM data. According to the city engineer, no corrections were necessary to the modeled flood extent. The historic downtown of Rock Springs was almost entirely inundated by the flood. Rock Springs is included in the Long-Term Recovery Plan (Wisconsin Recovery Task Force, 2008).

Kickapoo River at La Farge

The Kickapoo River flows south through the community of La Farge in southern Vernon County (appendix 3). For the La Farge area, a relatively coarse 10-m resolution DEM was all that was available, and a correction to the modeled inundated area in downtown La Farge was made on the basis of first-hand experience of the flood from the Village Public Works director (Wayne Carpenter, written commun., 2008) (appendix 3*B*). The USGS streamgage on the Kickapoo River at La Farge peaked at a gage-height elevation of 797.32 ft. The nearest high-water mark was on a tree approximately 70 ft from the streamgage, at an elevation of 797.3 ft. The agreement between the elevations of the high-water-mark and flood-peak gage-height confirms that the difference between the modeled and corrected inundation areas was caused by the coarse resolution of the topography from the 10-m DEM data. Expected vertical accuracy of the DEM is on the order of feet instead of tenths of feet expected for the high-water marks.

Figure 7. Flood inundation map and aerial photograph comparison for the June 2008 flood for north Reedsburg, Wisconsin. Note that the inundation map has been rotated to match the orientation of the aerial photograph. Inundation map base from U.S. Department of Agriculture (2006). Aerial photograph from the city of Reedsburg.

Kickapoo River at Gays Mills

The Kickapoo River flows south through the community of Gays Mills in Crawford County (appendix 4). Gays Mills experienced a record-breaking flood in August 2007, just 10 months before the June 2008 flood (fig. 6). The community still had several houses pending buyouts and businesses that had not yet reopened (Wisconsin Recovery Task Force, 2008). In August 2007, the west part of downtown was more heavily flooded (James Chellevold, Village of Gays Mills, oral commun., August 2008); but in June 2008, most of downtown Gays Mills was flooded.

The modeled inundated area for Gays Mills was inaccurate in the downtown area, based on first-hand experience of James Chellevold and town residents (Village of Gays Mills, written commun. 2008) (appendix 4*B*). Similar to the La Farge inundation maps, the coarse resolution of the available 10-m DEM used to build the topographic base of the inundation map was not accurate enough to delineate city-block-sized areas of the downtown that were topographically above the flood-peak elevation (appendix 4*B*). For example, several houses in the downtown area of Gays Mills were not inundated but were completely surrounded. Residents reported returning to little to no flood damage and a line of flood debris circling their homes, indicating that the residences were not flooded. The high-water-mark elevations near the NWS flood-stage forecasting site on the Kickapoo River in downtown Gays Mills were about 0.5 ft lower than the NWS flood peak gage height (fig. 6).

The heavy flooding on the east side of Gays Mills may have been due to a flash flood from an unnamed small tributary that enters the Kickapoo River valley on the northeast side of town and flows along Hagar Hallow Road. Depending on the timing and location of rain cells, this tributary may have enhanced the flooding on the east side of town, where the water flowed down State Highway 131 to Park Street. This is the area of town that was not flooded in August 2007 (James Chellevold, Village of Gays Mills, oral commun., August 2008).

Crawfish River at Milford

The Crawfish River flows south through the community of Milford in Jefferson County (appendix 5). Extensive and long-term flooding caused significant crop losses in the area upstream from Milford (Vic Imrie, Town Chair, Town of Milford, oral commun., August 2008). Because most of the town is on a local topographic high, relatively few structures or houses were damaged.

The modeled inundated area of flooding in Milford (appendixes 5*B* and 5*C*) is especially detailed because of the 3-m resolution of the Jefferson County DEM data. The USGS high-water marks were corroborated with nearby high-water marks surveyed by Jefferson County officials during the flood (not shown on appendix 5*B*). The high-water marks were corroborated with gage heights at the nearby USGS streamgage on the Crawfish River at County Highway A (table 3, appendix 5*B*). The streamgage had a flood-peak elevation of 792.7 ft. The high-water marks upstream and downstream from the streamgage/bridge were 792.8 and 791.8 ft, respectively. As with the La Farge and Gays Mills maps, the flood-peak-elevation checks show that the streamgage data corroborate the accuracy of the high-water marks. Similar to Reedsburg, the combination of verified high-water-mark data and 1-m DEM data resulted in accurate inundation maps.

Rock River at Jefferson

The Rock River flows south through the community of Jefferson in Jefferson County (appendix 6). The streamgage in Jefferson is on the south side of the bridge at South Main Street. The streamgage is operated by the National Weather Service and recorded a flood-peak elevation of 788.61 ft. The high-water mark near the streamgage house had an elevation of 788.6 ft, and the Jefferson County surveyor measured a flood-peak elevation of 788.57 ft on the road on the north side of the bridge. The three separate sources of data match well and, when combined with the high-resolution 1-m DEM, were used to produce a very detailed and accurate modeled inundation area. The city water treatment plant is near the streamgage and was not flooded, although floodwaters came close, according to city officials. Very little error was found in the modeled inundated area and the correction that was needed was due to recent construction at the south end of the reach.

Rock River at Fort Atkinson

The Rock River flows south and southwest through the community of Fort Atkinson in southern Jefferson County (appendix 7). The Rock River continues through Lake Koshkonong into Dane and Rock Counties. The reach ends at the USGS streamgage at Indianford, south of the town of Edgerton. The accuracy of the USGS high-water marks was corroborated with nearby high-water marks surveyed during the flood by Jefferson County officials. The streamgage recorded a flood-peak elevation of 782.5 ft. The surveyed elevation of the high-water mark on the streamgage house was 782.4 ft.

This reach of the Rock River and Lake Koshkonong covers three counties, which led to difficulties with matching digital datasets. Each county has high-resolution DEM available (3 m or better), but they did not match exactly along county lines. The reach was broken into three areas along the county boundaries in order to facilitate the modeling. The edges of the extent of modeled inundated area matched adequately and the three areas were merged (appendix 7*B*). The flood-depth grid could not be merged, so the results of model runs for the three counties are presented separately in appendix 7*C*. Very little error was found in the modeled inundated area, and the small correction that was needed was due to recent construction on the north side of Lake Koshkonong and to some low-lying areas in South Fort Atkinson that were not in hydraulic connection with the floodwaters. The area south of Lake Koshkonong, near Edgerton, was not checked by city or county officials. The modeled and corrected inundation areas can be viewed as a good representation of the extent of flooding, but depths should be interpreted with caution, bearing in mind the limitation due to the use of digital data from the three counties.

Rock River at Janesville

The Rock River runs south through the community of Janesville in central Rock County (appendix 8). The modeled inundated area of flooding is especially detailed because of the 1-m-resolution DEM data that were created from 2-ft topographic contours in the Janesville area. The accuracy of the USGS high-water marks was corroborated with nearby high-water marks surveyed during the flood by Janesville officials (appendix 8*A*). The city of Janesville has a high floodwall that was able to protect much of the downtown. Where the stream spilled over the floodwall on the upstream, north side of the city center, it was contained with sandbags and safely flowed down Main Street and inundated different areas than are shown in the modeled inundated area (appendix 8*B*). City officials provided the corrected inundated area on the basis of actual flood conditions in downtown Janesville.

Rock River at Beloit

The Rock River runs south through the city of Beloit in southern Rock County and into northern Illinois (appendix 9). The modeled inundated area of flooding is very detailed because of the 1-m-resolution DEM data that were created from 2-ft topographic contours of the Beloit area. For the portion of the reach in Illinois, a 1-m DEM was obtained and combined with the city of Beloit data during data processing. Flooding in Beloit was similar to that in Janesville: a floodwall and dam protected much of the city, and the areas that otherwise might have flooded were protected with sandbags. Areas below the dam that were modeled as inundated were corrected by the city engineer.

Flood Damages and Impacts

The immediate impact of the heavy rainfall on saturated ground on June 7 and 8 was widespread flash flooding. Thousands were evacuated. Tornadoes in Columbia County caused extensive damage. In the early afternoon on June 7, water was reported on Interstate 39 in Columbia County. The second wave of storms on June 12 and 13 caused further road closings on Interstates 94, 90-94, and 39, as well as on 30 State Highways (Stein and Adams, 2008). Transportation became extremely difficult as major arteries between Madison, Milwaukee, Chicago, and Minneapolis were shut down for 1–2 weeks. Interstate 90-94 between Milwaukee and Madison reopened on June 20, and Interstate 39 near the Wisconsin Dells reopened on June 21. Numerous local highways and roads were washed out or flooded and closed. Property damage was extensive. Railroad embankments were washed out or flooded. Airports were closed. About 200 people in Baraboo were rescued from homes and businesses by refurbished World War II amphibious vehicles used by companies that provide tours of the Wisconsin River and nearby areas (Novotny, 2008). Throughout the region, people were sandbagging to protect homes and businesses from rising water. At least 161 communities were forced to divert untreated sewage around their overwhelmed treatment plants (Wisconsin State Journal, 2008). Crop losses alone were estimated to be $300–$400 million (Wisconsin Recovery Task Force, 2008). Along the Crawfish and Rock Rivers, some businesses and industry had to shut down by June 11 and could not reopen for weeks because of extended flooding along these streams that lasted into July (fig. 5). Lake Delton catastrophically drained into the Wisconsin River from a land breach along a narrow area of shoreline between the lake and river on June 9. The land breach of Lake Delton resulted in the immediate loss of entire houses at the breach to the Wisconsin River and caused extended loss of recreational use to riparian businesses and homeowners along the heavily populated lakefront.

By June 20, flood damages were estimated at $470.5 million for businesses, homes, public infrastructure, and agriculture (Stein, 2008). Later assessments estimated the damages to be much higher. A partial list of the costs in the Wisconsin Recovery Task Force Damage report issued in September totaled greater than $1.5 billion (Wisconsin Recovery Task Force, 2008). The Governor of Wisconsin asked the Federal government for additional funding to aid in the cleanup, estimating that $1.2 billion was still needed for housing, business, and infrastructure needs (Associated Press, 2008).

Important Findings Relative to Study Methods

Usually, high-water marks are flagged immediately following a flood and surveyed shortly after. For this study, the 2-month delay in flagging high-water marks did not cause a problem because mud, water, and debris lines still were prevalent in all the communities due to the extreme magnitude and duration of the flooding. Cleanup efforts had not begun or were still in progress in the communities during the high-water-mark-data collection. Abundant mud and water-stain lines were still visible on buildings, railings, trees, posts, fences, and other objects in urban areas. Overall, mud and stain lines on buildings were more reliable and consistent in urban areas than flood trash and debris lines in trees in rural areas. High-water mark crews were able to choose the most representative mark among many available at one location, increasing the level of confidence in the high-water marks.

Use of the RTK-GPS, a relatively new technology for the USGS in surveying high-water marks, proved highly successful. The RTK-GPS decreased surveying time, increased the areal extent that could be surveyed, and allowed high-population areas to be mapped with greater accuracy than by conventional surveying methods. The high-water mark flagging and survey took approximately 90 person-days to complete 40 mi with 377 high-water marks. The resolution of the RTK-GPS surveys was greater than 0.1-ft because (1) the survey equipment was located for maximum satellite reception and radio coverage, and (2) a minimum of two control points was surveyed with multiple repeated readings. In urban settings, many control points were available, and the possibility of setting up on tall buildings maximized satellite reception and increased the distance covered by radio signal.

Utility of DEM data as the topographic base for the inundation maps was highly dependent on the resolution of the DEM data. High-resolution DEMs (less than 5 m) were available for seven out of the nine communities included in this study. Commonly, 10-m-resolution DEM is considered high resolution; however, for the purposes of this study, 10 m was shown to be too coarse to produce detailed modeled inundated areas. If higher resolution DEM data for La Farge and Gays Mills had been available, it would have improved the accuracy of the modeled inundated area.

The GIS-derived flood maps and profiles outline the extent and depth of flooding through the communities and are currently (2008) being used in flood-response and recovery efforts by local, county, State, and Federal agencies. As high-resolution digital elevation data become more available, future flood-inundation maps could be used for predicting flood-hazard areas, protecting critical infrastructure, and safeguarding emergency-response capabilities in communities upstream from real-time USGS streamgages. Flood-inundation maps and profiles are beneficial for FEMA flood-map validation as the National Flood Insurance Map Modification Program moves forward. Lastly, flood maps and profiles can be used to expand flood-warning and flood-forecast products delivered by the National Weather Service Advance Hydrologic Prediction Service.

Summary and Conclusions

Heavy rain in June 2008, combined with saturated soils, caused record flooding in southern Wisconsin. The flooding caused immediate evacuations, road closures, and prolonged, extensive damages and losses associated with agriculture, businesses, housing, public health and human needs, and infrastructure and transportation. Thirty-one counties were declared disaster areas. Rainfall amounts for durations of 24 hours, 48 hours, 7 days, and 1 month exceeded records at several precipitation stations. Extensive flooding along the Baraboo River, Kickapoo River, Crawfish River, and Rock River caused particularly severe damage in nine communities and their surrounding areas: Reedsburg, Rock Springs, La Farge, Gays Mills, Milford, Jefferson, Fort Atkinson, Janesville, and Beloit. Given the severity of the flooding, the U.S. Geological Survey (USGS), in cooperation with the Federal Emergency Management Agency, did a study to document the meteorological and hydrological conditions leading to the flood; compile flood-peak gage heights, streamflows, and flood probabilities at USGS streamgage and at selected ungaged locations; construct flood-peak inundation maps and flood profiles; and summarize flood damages and impacts.

Record gage heights and streamflows occurred at 21 USGS streamgages in southern Wisconsin. Flood probabilities at the streamgages with record gage-height or streamflow ranged from 0.002 to 0.04 (range based on 95-percent confidence intervals). Five streamgages had estimated flood probability ranges of 0.005 or less based on the 95-percent confidence intervals.

The USGS flagged and surveyed 377 high-water marks in August 2008 in 9 communities along reaches of the Kickapoo River, Baraboo River, Crawfish River, and the Rock River totaling 40 mi. Flood-peak inundation maps and water-surface profiles were modeled for the nine communities in a geographic information system by combining high-water marks with the highest resolution digital-elevation-model data available for each community. The 189 high-water marks used in compiling the flood-peak inundation maps were a combination of a subset of USGS high-water marks and those surveyed during the June flood by communities, counties, and Federal agencies. Mud and stain lines still were prevalent in August in all the communities because of the extreme magnitude and duration of the flooding. The flood-peak inundation maps were verified and corrected if needed through multiple sources of flood photographs and documentation by community officials.

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References Cited

Associated Press, 2008, Governor asks for more federal flood help: Winona [Minn.] Daily News, September 18, 2008.

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

Channel 3000, 2008, Interstate 94 reopens between Madison, Milwaukee: Madison, Wis., accessed June 20, 2008, at http://www.channel3000.com/news/16656192/detail.html

Dalrymple, Tate, and Benson, M.A., 1967, Measurement of peak discharge by the slope-area method: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A2, 12 p.

Davidian, Jacob, 1984, Computation of water-surface profiles in open channels: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A15, 48 p.

Fulford, J.M., 1994, User's guide to SAC, a computer program for computing discharge by slope-area method: U.S. Geological Survey Open-File Report 94–360, 31 p.

Huff, F.A., and Angel, J.R., 1992, Rainfall frequency atlas of the Midwest: Champaign, Ill., Illinois State Water Survey Bulletin 71, 141 p.

Hughes, P.E., Hannuksela, J. S., and Danchuk, W. J., 1981, Flood of July 1-5, 1978 on the Kickapoo River, southwestern Wisconsin: U.S. Geological Survey Hydrologic Atlas 653, 6 maps on seven sheets.

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

Langbein, W.B., and Iseri, K.T., 2008, Manual of hydrology, Part 1, general surface-water techniques—General introduction and hydrologic definitions: U.S. Geological Survey Water-Supply Paper 1541–A, accessed September 6, 2008, at http://water.usgs.gov/wsc/glossary.html

Midwestern Regional Climate Center, 2008, Midwest overview—June 2008: Midwest Climate Watch Highlights and Reports, accessed October 29, 2008 at http://mrcc.sws.uiuc.edu/cliwatch/0806/climwatch.0806.htm

Morlock, S.E., Menke, C.D., Arvin, D.V., and Kim, M.H., 2008, Flood of June 7–9, 2008, in central and southern Indiana: U.S. Geological Survey Open File Report 2008–1322, 15 p., 3 app.

National Climatic Data Center, 2008, Climate of 2008—Midwestern U.S. flood overview: Accessed October 30, 2008, at http://www.ncdc.noaa.gov/oa/climate/research/2008/flood08.html

National Weather Service, 2008, Heavy rainfall and flooding information from early June (2 PM 6/24): accessed October 31, 2008, at http://www.crh.noaa.gov/news/display_cmsstory.php?wfo=mkx&storyid=14030&source=0

Novotny, Andrea, 2008, Original Wisconsin Ducks come to the rescue in Baraboo flood—Two hundred residents evacuated by Duck: Wisconsin Dells, Wis., Novotny Communications press release, June 13, 2008, accessed November 20, 2008, at http://www.wisconsinducktours.com/media/Ducks%20Flood%20Rescue%20Release.pdf

Rantz, S.E., and others, 1982, Measurement and computation of streamflow—Volume 1, Measurement of stage and discharge, and volume 2, Computation of discharge: U.S. Geological Survey Water-Supply Paper 2175, 631 p.

Stein, Jason, 2008, The flood of ‘08—Many a job put on hold: Wisconsin State Journal, June 20, 2008.

Stein, Jason, and Adams, Barry, 2008, Road closings make for a giant headache: Madison, Wis., Wisconsin State Journal, June 14, 2008, p. A1.

U.S. Department of Agriculture, 2006, National Agriculture Imagery Program (NAIP) information sheet: Accessed October 31, 2008, at http://www.fsa.usda.gov/Internet/FSA_File/naip_final_2006_updatep.pdf

U.S. Census Bureau, 2000, Profiles of General Demographic Characteristics: 2000 Census of Population and Housing, Wisconsin, accessed October 2008 at URL http://www.census.gov/prod/cen2000/dp1/2kh55.pdf

Walker, J.F., and Krug, W.R., 2003, Flood-frequency characteristics of Wisconsin streams: U.S. Geological Survey Water-Resources Investigations Report 03–4250, 37 p.

Wisconsin Recovery Task Force, 2008, Report to the Governor on FEMA–1768–DR–WI, Severe storms, tornadoes, and flooding: Wisconsin Emergency Management Report [Draft October 31, 2008].

Wisconsin State Journal, 2008, Floods of 2008: Madison, Wis., June 27, 2008, special section.

Appendixes

Results for the June 2008 flood for selected sites in Wisconsin are shown in appendixes 1–9. Each appendix has four parts grouped by community and reach

(A) High-water mark Table
(B) Flood-Peak Extent Inundation Map
(C) Flood-Depth Map
(D) Flood-Peak Water-Surface Profile

Appendix data can be accessed by downloading files at http://pubs.usgs.gov/sir/2008/5235

Appendix 1. Baraboo River at Reedsburg

Appendix 2. Baraboo River at Rock Springs

Appendix 3. Kickapoo River at La Farge

Appendix 4. Kickapoo River at Gays Mills

Appendix 5. Crawfish River at Milford

Appendix 6. Rock River at Jefferson

Appendix 7. Rock River at Fort Atkinson

Appendix 8. Rock River at Janesville

Appendix 9. Rock River at Beloit

Glossary

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

Backwater. Water backed up or retarded in its course as compared with its normal or natural condition of flow. In stream gaging, a rise in stage produced by a temporary obstruction such as ice or weeds, or by the flooding of the stream below. The difference between the observed stage and that indicated by the stage-discharge relation, is reported as backwater.

Cubic feet per second. A unit expressing rates of discharge. One cubic foot per second is equal to the discharge of a stream of rectangular cross section, 1 foot wide and 1 foot deep, flowing water an average velocity of 1 foot per second.

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 plain. A strip of relatively smooth land bordering a stream, built of sediment carried by the stream and dropped in the slack water beyond the influence of the swiftest current. It is called a living flood plain if it is overflowed in times of high water; but a fossil flood plain if it is beyond the reach of the highest flood.

Flood plane. The position occupied by the water surface of a stream during a particular flood. Also, loosely, the elevation of the water surface at various points along the stream during a particular flood.

Flood probability. The probability that a given event magnitude will be exceeded or equaled in any given year. Flood probability is directly related to 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.

Flood profile. A graph of elevation of the water surface of a stream 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.

Frontal boundary. A boundary or transition zone between two air masses of different density, and thus (usually) of different temperature. A moving front is named according to the advancing air mass; for example, cold front if colder air is advancing (National Weather Service, 2005).

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 streamgage.

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 one divided by the flood probability. For example, a 100-year recurrence interval has a flood probability of 0.01.

Stationary front. A front between warm and cold air masses that is moving very slowly or not at all. (National Weather Service, 2005).

Stream. A general term for a body of flowing water. In hydrology the term is generally applied to the water flowing in a natural channel as distinct from a canal.

Streamflow. The discharge that occurs 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.

Stream gaging. The process and art of measuring the depths, areas, velocities, and rates of flow in natural or artificial channels.

Streamgage. A gaging station where a record of discharge of a stream is obtained. Within the U.S. Geological Survey, this term is used only for those gaging stations where a continuous record of gage-height is obtained.

Water year. In U.S. Geological Survey reports dealing with surface-water supply, the 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends and that includes 9 of the 12 months. Thus, the year that ended September 30, 2008, is called “water year 2008.”

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