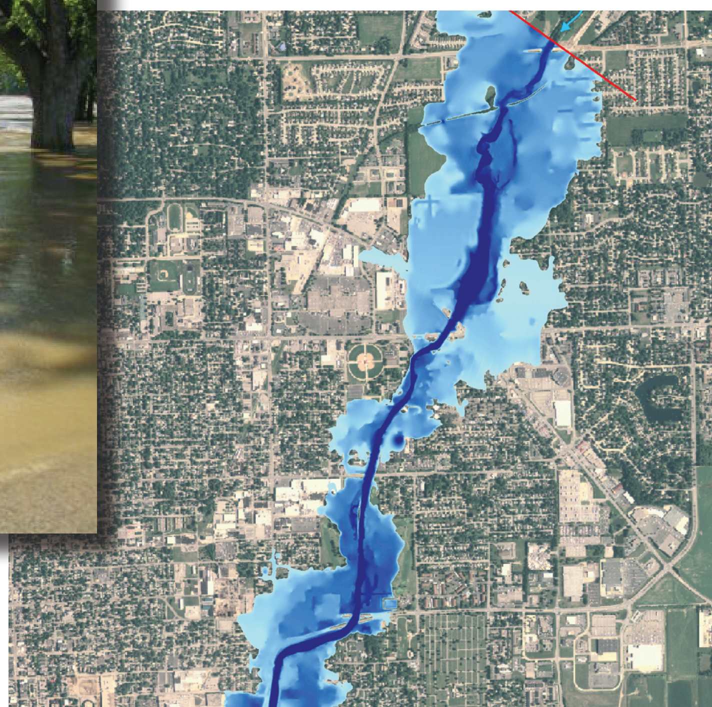
In Cooperation with the Federal Emergency Management Agency and the Indiana Department of Natural Resources, Division of Water

Flood of June 7–9, 2008, in Central and Southern Indiana



Open-File Report 2008–1322

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

Cover images: Home flooded by the White River near Spencer, Indiana, June 9, 2008 (photograph by Chad Menke, U.S. Geological Survey) and part of an inundation map showing approximate flood-peak extents and depths, June 7–9, 2008, for Haw Creek at Columbus, Indiana (entire map is in Appendix 2 of the report).

Flood of June 7–9, 2008, in Central and Southern Indiana

By Scott E. Morlock, Chad D. Menke, Donald V. Arvin, and Moon H. Kim

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U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

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Conversion Factors, Datums, and Abbreviations

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	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
	Volume	
cubic foot (ft^3)	28.32	cubic decimeter (dm^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	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 elevation (altitude) 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).

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

Abbreviations

AML	Arc macro language
DEM	Digital elevation model
EDT	Eastern Daylight Time
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
IDHS	Indiana Department of Homeland Security
IDNR	Indiana Department of Natural Resources
NAVD 88	North American Vertical Datum of 1988
NGVD 29	National Geodetic Vertical Datum of 1929
NWS	National Weather Service
TIN	Triangular irregular network
USGS	U.S. Geological Survey

Flood of June 7–9, 2008, in Central and Southern Indiana

By Scott E. Morlock, Chad D. Menke, Donald V. Arvin, and Moon H. Kim

Abstract

On June 6–7, 2008, heavy rainfall of 2 to more than 10 inches fell upon saturated soils and added to already high streamflows from a wetter than normal spring in central and southern Indiana. The heavy rainfall resulted in severe flooding on many **streams** within the White River Basin during June 7–9, causing three deaths, evacuation of thousands of residents, and hundreds of millions of dollars of damage to residences, businesses, infrastructure, and agricultural lands. In all, 39 Indiana counties were declared Federal disaster areas.

U.S. Geological Survey (USGS) streamgages at nine locations recorded new record peak **streamflows** for the respective periods of record as a result of the heavy rainfall. **Recurrence intervals** of flood-peak streamflows were estimated to be greater than 100 years at five streamgages and 50–100 years at two streamgages. Peak-gage-height data, peak-streamflow data, and recurrence intervals are tabulated for 19 USGS streamgages in central and southern Indiana. Peak-streamflow estimates are tabulated for four ungaged locations, and estimated recurrence intervals are tabulated for three ungaged locations. The estimated recurrence interval for an ungaged location on Haw Creek in Columbus was greater than 100 years and for an ungaged location on Hurricane Creek in Franklin was 50–100 years. Because flooding was particularly severe in the communities of Columbus, Edinburgh, Franklin, Paragon, Seymour, Spencer, Martinsville, Newberry, and Worthington, high-water-mark data collected after the flood were tabulated for those communities. **Flood peak** inundation maps and water-surface profiles for selected streams were made in a geographic information system by combining the high-water-mark data with the highest-resolution digital elevation model data available.

Introduction

Flood data are 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), Indiana Department of Natural Resources (IDNR), and Indiana Department of Homeland Security (IDHS) need timely information on the magnitudes and recurrence intervals of floods to help respond to flood damage, preserve emergency response management, protect infrastructure, provide recovery guidance from the National Flood Insurance Program and State regulatory programs, and plan for future flood events.

Heavy rains caused severe flooding on June 7–9, 2008, in parts of central and southern Indiana. Rainfall amounts from about 2 in. to more than 10 in. fell in south-central Indiana on June 6–7 (Shipe, 2008), causing the National Weather Service (NWS), by June 9, to issue 21 flash-flood warnings, 10 areal flood warnings, and 10 river flood warnings and statements (David Tucek, National Weather Service, written commun., August 2008). A state of emergency was declared on June 7 in the affected areas; and during June 7–9, there were numerous evacuations and water rescues in communities affected by the flooding. Flood impacts were particularly severe in communities in Bartholomew, Greene, Johnson, Morgan, Owen, Vermillion, and Vigo Counties. The flooding caused three fatalities, major transportation disruptions, damage to thousands of homes and businesses, damage to dams and flood-control structures, and damage to critical facilities, including utilities and two hospitals (Shipe, 2008). Damage caused by the flooding, and other damage caused by severe storms, resulted in a Presidential Disaster Declaration for 39 Indiana counties (Federal Emergency Management Agency, 2008).

Given the severity of the June 2008 flooding in Indiana, the U.S. Geological Survey (USGS), in cooperation with the FEMA and the IDNR, Division of Water, did a study to document the meteorological and hydrological conditions leading to the flood; compile flood-peak gage heights, streamflows, and recurrence intervals at USGS streamgages and estimate streamflows and recurrence intervals at selected ungaged locations; construct flood profiles and peak-stage inundation maps; and summarize flood damages and impacts.

Purpose and Scope

The purpose of this report is to present the results of the study. The meteorological and hydrologic conditions leading to the floods are discussed. Meteorological data were provided by the NWS and the Indiana State Climate Office, and hydrologic-condition information was obtained from streamflow data at USGS streamgages. Peak-gage-height and peak-

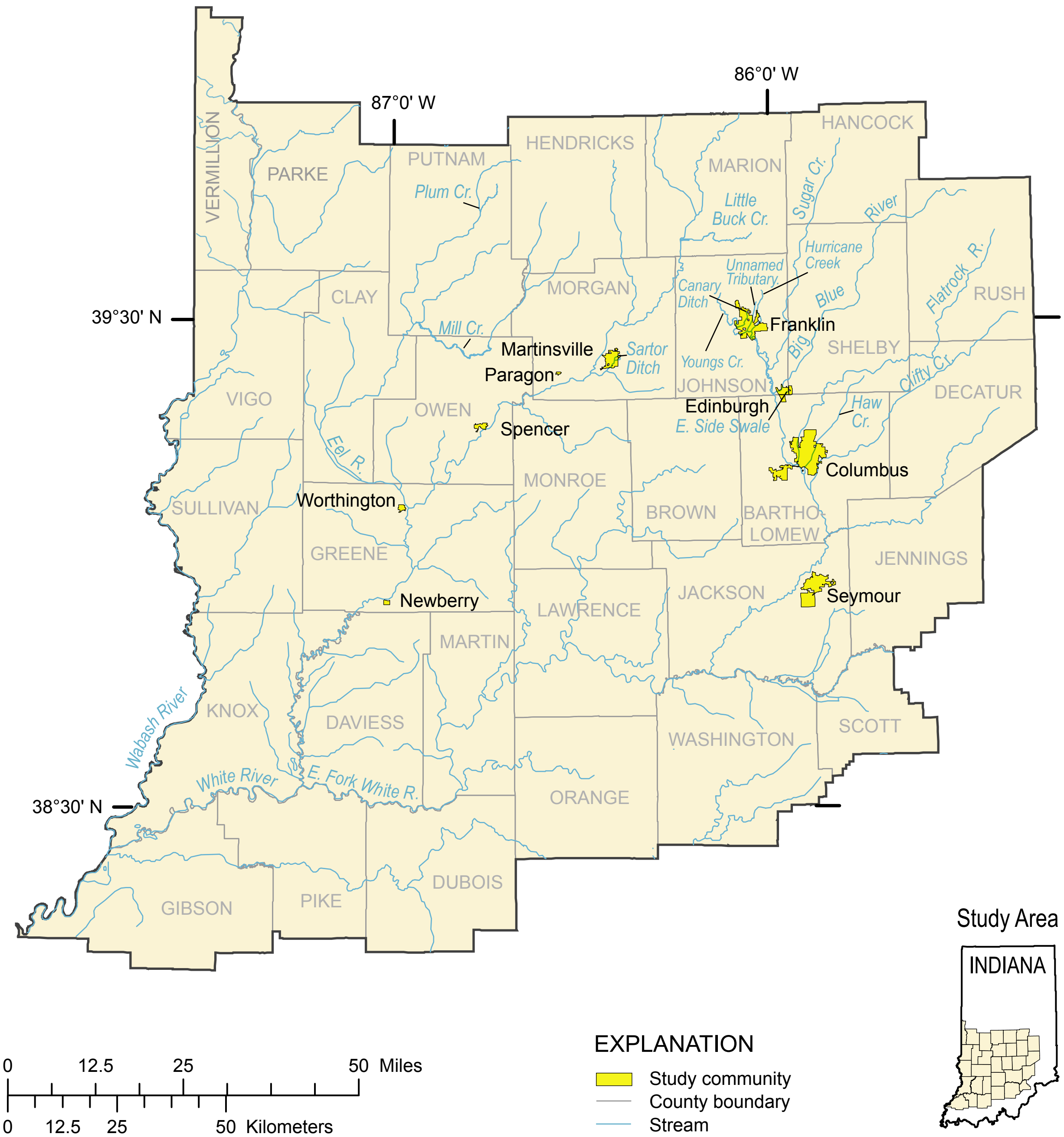

Figure 1. Study area in central and southern Indiana.

streamflow data are presented for 19 active USGS streamgages and peak-streamflow data are presented for 4 ungaged locations (locations on streams that do not have an active streamgage). High-water marks set by the IDNR and the USGS were surveyed to obtain water-surface elevations for about 50 mi of streams in nine communities (fig. 1). The streams, all within the White River Basin of Indiana, include Blue River, Canary Ditch, Clifty Creek, East Fork White River, East Side Swale, Eel River, Flatrock River, Haw Creek, Hurricane Creek, an unnamed tributary of Fall Creek at Paragon, an unnamed tributary of Youngs Creek at Franklin, Youngs Creek, and White River. The communities include Columbus, Edinburgh, Franklin, Martinsville, Newberry, Paragon, Seymour, Spencer, and Worthington. The high-water-mark data were used to produce flood-peak inundation maps and flood profiles for selected streams in the communities studied. Information for the flood damage and impact summary was furnished by FEMA, NWS, IDHS, IDNR, the Indiana Office of Disaster Recovery, local agencies, news accounts and photographs, and corroborated testimony from individuals in affected communities.

Conditions Leading to the Flood

The June flooding in Indiana was caused by heavy rain falling upon saturated soils at a time when streamflows already were much above normal. A wetter than normal spring preceded the June flood in Indiana. Precipitation totals in central and southern Indiana for the period March–May 2008 ranged from 123 to 180 percent of normal (Indiana State Climate Office, 2008). Rainfall amounts of 1–3 in. on May 30–31 and 1–5 in. on June 3–4 in parts of central and southern Indiana resulted in above-normal streamflows in the days prior to the June flood (National Weather Service, 2008). On the basis of the USGS WaterWatch Recent Streamflow Conditions map for June 5, 2008, daily mean streamflows at many USGS streamgages in central and southern Indiana (with 30 or more years of record) were either much above normal or were record highs for June 5 (U.S. Geological Survey, 2008). On June 6, an abnormally high amount of moisture from the Gulf of Mexico was available for thunderstorms, and a nearly stationary frontal boundary was in place across south-central Indiana to enhance thunderstorm development and anchor a common storm path (David Tucek, National Weather Service, written commun., June 2008). A strong inflow of Gulf moisture, lifted by the frontal boundary, resulted in frequent to nearly continuous showers and thunderstorms of moderate to heavy rainfall intensity for 12 to 16 hours on June 6–7 (David Tucek, National Weather Service, written commun., August 2008).

A map of estimated precipitation totals prepared from NWS radar data (Thomas Adams, National Weather Service Ohio River Forecast Center, written commun., 2008) shows rainfall totals ranging from about 2 in. to more than 10 in. for June 6–7 across south-central Indiana (fig. 2). Rainfall in most locations fell between about 6:00 p.m. Eastern Daylight Time (EDT) on June 6 and about 1:00 p.m. EDT on June 7. Provisional total rainfall amounts for June 6–7 from selected NWS precipitation stations (table 1, fig. 2) ranged from 6.1 in. at Jasonville, Greene County, to 10.4 in. at Spencer, Owen County. Average recurrence intervals[1] (Bonnin and others, 2006), given in total rainfall amount for a 24-hour duration, are presented in table 1. Average recurrence intervals were greater than 50 years at Jasonville, Greene County; greater than 100 years at Brazil, Clay County; greater than 500 years at Martinsville, Morgan County, and Franklin, Johnson County; and greater than 1,000 years at Spencer, Owen County. A plot of hourly cumulative rainfall (fig. 3) at the Spencer precipitation station illustrates the rainfall pattern for the period 8:00 a.m. EDT June 6 to 11:00 a.m. EDT June 7. The slope of the line is indicative of rainfall rates; a steeper slope indicates higher rates.

[1] The recurrence interval is the average interval of time within which the given event will be equaled or exceeded once (American Society of Civil Engineers, 1953, p. 1221). For example, the 100-year rainfall is the rainfall that would be exceeded or equaled, on long-term average, once in 100 years. Recurrence interval relates the magnitude of an event to a probability of occurrence and does not imply that the event will happen at regular intervals; for example, two 100-year floods can occur within the same year at the same location. The reciprocal of the recurrence interval is the **annual exceedance probability**, which is the probability that a given event magnitude will be exceeded or equaled in any given year (Hodgkins and others, 2007). For example, the annual exceedance probability of the 100-year peak flood streamflow is 0.01. In other words, there is a 1-percent chance that the 100-year peak flow will be exceeded or equaled in any given year.

Table 1. Provisional total rainfall for June 6–7, 2008, and average-recurrence-interval rainfalls for a 24-hour duration at selected National Weather Service precipitation stations.

[Provisional total rainfall provided by National Weather Service (Al Shipe, written commun., July 2008). Average recurrence intervals from Bonnin and others (2006)]

Site name	County	Total rainfall (inches)	Average-recurrence-interval rainfall for 24-hour duration (inches)				
			50-year	100-year	200-year	500-year	1,000-year
Spencer	Owen	10.4	5.7	7.0	7.8	9.0	10.0
Martinsville	Morgan	8.2	5.7	6.3	7.0	7.9	8.6
Franklin	Johnson	7.6	5.3	5.9	6.4	7.2	7.8
Brazil	Clay	7.0	6.1	6.9	7.7	8.9	9.9
Jasonville	Greene	6.1	5.9	6.6	7.3	8.2	9.0

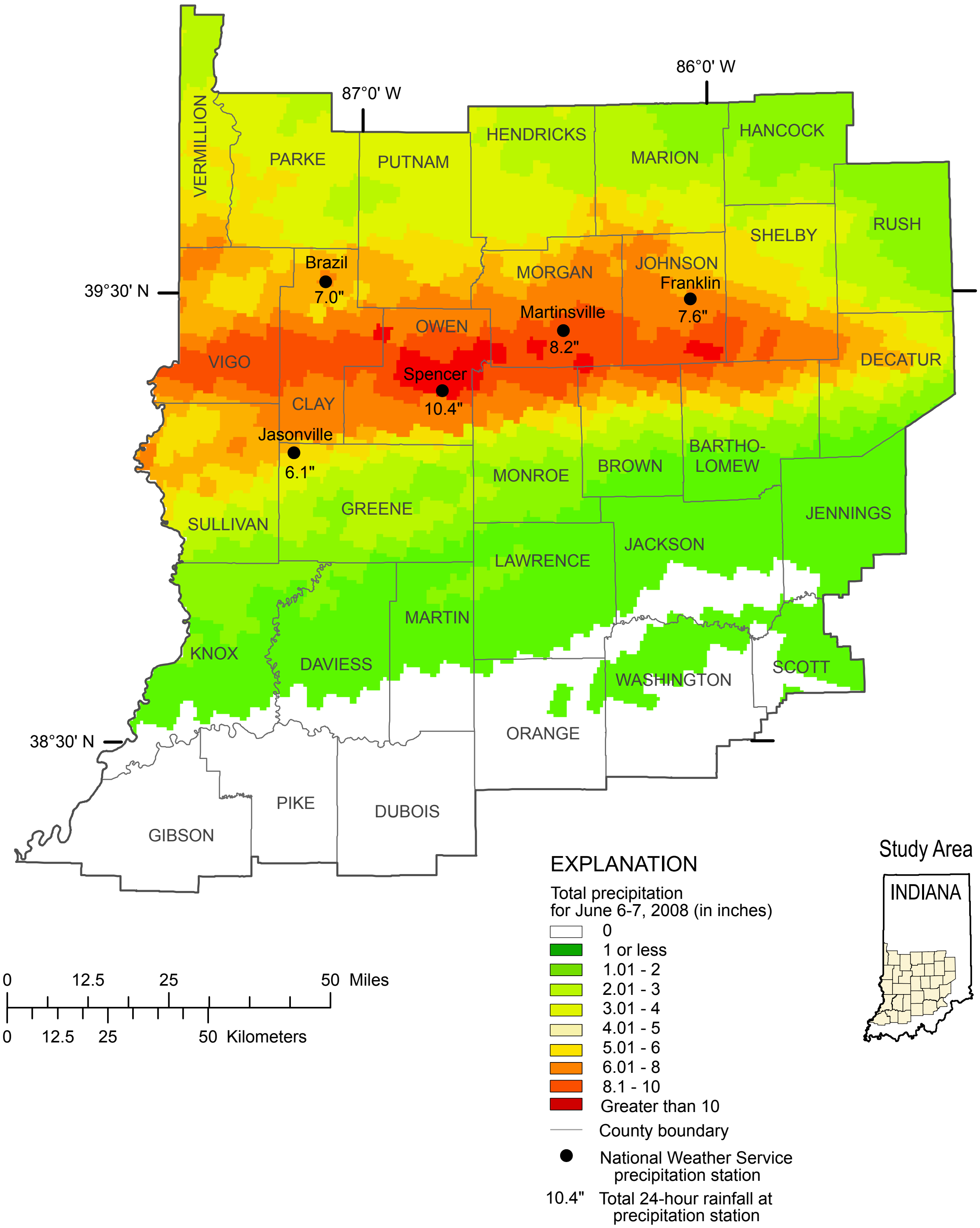

Figure 2. Distribution of rainfall totals June 6–7, 2008, and provisional rainfall totals for the National Weather Service stations (by station name) listed in table 1. Rainfall-distribution data provided by the National Weather Service (Thomas Adams, National Weather Service Ohio River Forecast Center, written commun., 2008).

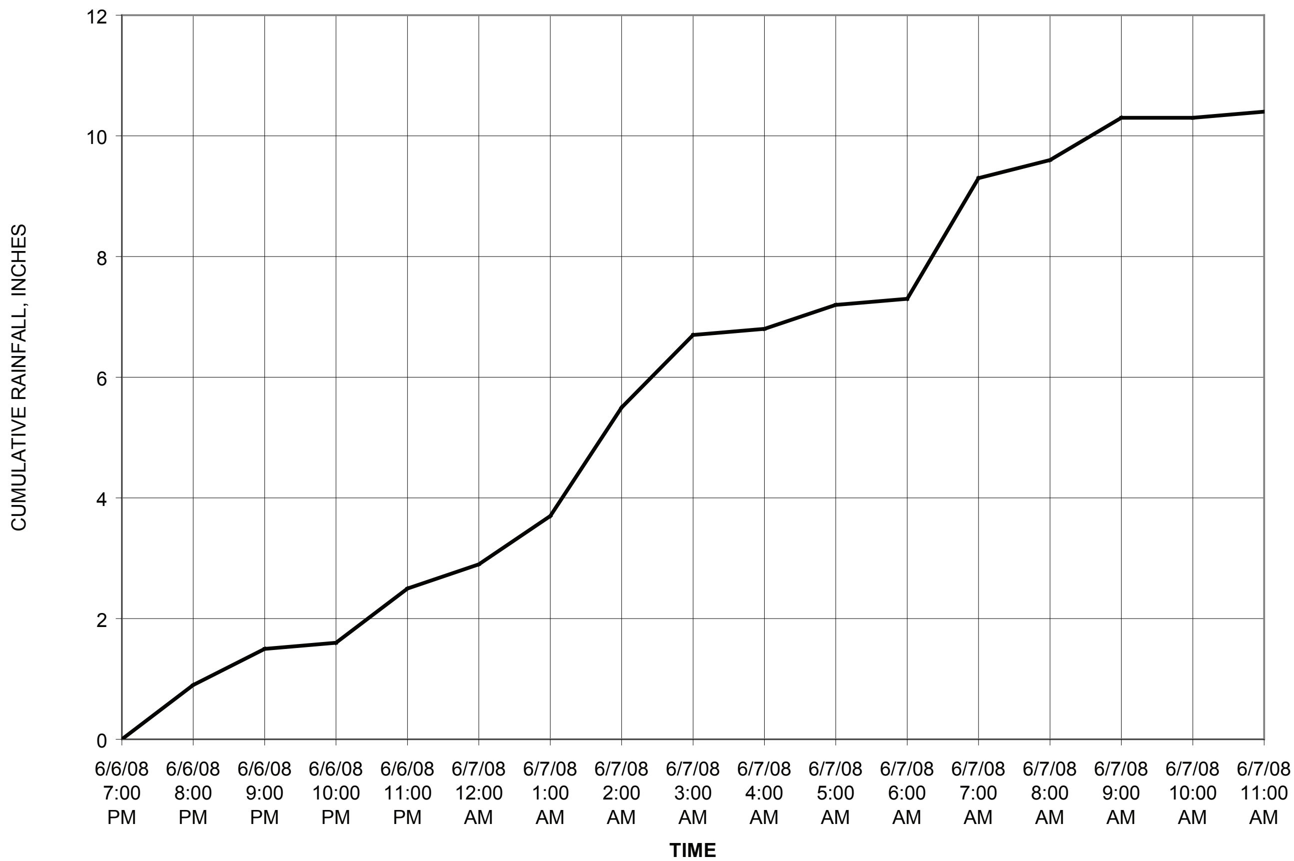

Figure 3. Cumulative hourly rainfall during June 6–7, 2008, recorded at the National Weather Service precipitation station at Spencer, Owen County, Indiana.

Collection of High-Water-Mark Data

High-water marks were identified and flagged in the field by IDNR and USGS field crews after floodwaters receded. High-water marks were set along approximately 240 mi of streams after the floods. For this study, high-water marks were fully documented for about 50 stream miles on the following streams: Blue River, Canary Ditch, Clifty Creek, East Fork White River, East Side Swale, Eel River, Flatrock River, Haw Creek, Hurricane Creek, an unnamed tributary of Fall Creek at Paragon, an unnamed tributary of Youngs Creek at Franklin, Youngs Creek, and White River (fig.1). The IDNR, USGS, and IDHS collectively determined the areas where high-water marks were to be flagged in order to effectively document the flooding. The accuracy of high-water marks was rated subjectively by field personnel as “excellent,” “good,” “fair,” or “poor” according to guidelines of Lumia and others (1986). “Excellent” means the reported high-water mark is within 0.02 ft of the true high-water elevation; “good” within 0.05 ft; “fair” within 0.10 ft; and “poor” less than “fair” accuracy.

High-water marks at each site were surveyed to obtain peak-water-surface elevations and were referenced to North American Vertical Datum of 1988 (NAVD 88). High-water-mark descriptions, locations (latitude and longitude), and accuracy ratings are presented in Appendix 1.

Methods of Estimating the Magnitudes and Recurrence Intervals of Peak Streamflows

Estimation of Magnitudes

Peak streamflows documented in this study were determined at 19 USGS streamgages (table 2, fig. 4) by use of the rating curve (the relation between river height and flow) for each station. Rating curves at streamgages are developed by relating gage height to streamflow for a range of flows (Rantz and others, 1982). Streamflow data points used to develop a rating are determined most commonly by direct measurement at the gage; or, if direct measurement is not possible, by indirect methods. The rating curve is interpolated between 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 (Sherwood and others, 2007).

Peak gage heights (table 2) were obtained either from electronic data recorders or from surveyed high-water marks where recorders or stage sensors malfunctioned. The rating curve was used to compute peak streamflow (table 2) from peak gage height. Direct streamflow measurements or stream-

Table 2. Flood-peak gage heights, peak streamflows, and estimated recurrence intervals during the flood of June 7–9, 2008, at selected U.S. Geological Survey streamgages in Indiana. (Streamgage locations are shown in figure 4.)

[mi^2, square miles; ft, feet; ft^3/s, cubic feet per second; Q, streamflow; GH, gage height; YR, year; <, less than; >, greater than]

						Peak flow for period of record prior to June 2008			Peak flow for June 2008						
Station number	Station name	Drain-age area (mi^2)	Gage vertical datum (feet NGVD 29)	Period of record (water years)[1]	Length of record of annual peaks (years)	Date	Gage height (feet above gage datum)	Stream-flow (ft^3/s)	Date	Gage height (feet above gage datum)	Stream-flow (ft^3/s)	Estimated recurrence-interval range for June 2008 peak streamflow (years)	Esti-mated[2] 100-year peak stream-flow (ft^3/s)	Historic larger peaks outside period of record	Comments
03341500	Wabash River at Terre Haute, IN	12,263	445.78	1928-2008	81	5/20/1943	30.5 (0.6 mile downstream at datum 442.90)	189,000	6/8/2008	25.02	92,400	< 10	[3] 154,000	1913 peak GH=31.2 ft (at current datum), Q=245,000 ft^3/s	Moderate regulation at high flow by upstream reservoirs.
03342000	Wabash River at Riverton, IN	13,161	414.65	1939-2008	70	5/21/1943	29.36	201,000	6/10/2008	26.56	98,100	< 10	[3] 157,000	1913 peak GH=26.4 ft, Q=250,000 ft^3/s	Moderate regulation at high flow by upstream reservoirs.
03353637	Little Buck Creek near Indianapolis, IN	17	666.2	1990-2008	19	12/30/1990	[4] 9.10	2,300	6/7/2008	13.01	[8] 2,850	< 10	[3] 7,230		
03354000	White River near Centerton, IN	2,444	595.44	1931-1932,1947-2008	64	9/2/2003	20.04	65,700	6/7/2008	19.85	63,500	50-100	[3] 71,100	1913 peak GH=21.9 ft 0.4 mile downstream (at current datum), Q=90,000 ft^3/s	Minor reguation at high flow by upstream reservoirs.
03357000	White River at Spencer, IN	2,988	526.04	Q 1926-1971, GH 1988-2008	47	5/15/1933	[5] 23.20	[6] 59,400	6/8/2008	26.84	[7] 63,500	25-50	[3] 80,300	1913 peak GH=28.5 ft	
03357350	Plum Creek near Bainbridge, IN	3	828.44	1970-2008	39	9/14/1989	6.50	940	6/4/2008	7.15	[8] 1,000	25-50	[9] 1,180		
03358000	Mill Creek near Cataract, IN	245	706.4	1950-2008	59	12/30/1990	Unknown	12,200	6/7/2008	22.61	10,800	10-25	[9] 14,000		
03360500	White River at Newberry, IN	4,688	465.59	1929-2008	80	11/18/1993	[10] 25.87	105,000	6/9/2008	28.59	[8] 138,000	> 100	[3] 106,000	1913 peak GH=27.5 ft, Q=130,000 ft^3/s	Minor regulation at high flow by upstream reservoirs.
03362000	Youngs Creek near Edinburgh, IN	107	670.2	1944-2008	65	1/27/1952	13.40	10,700	6/7/2008	15.67	[8] 20,500	> 100	[3] 13,400		
03362500	Sugar Creek near Edinburgh, IN	474	646.23	1944-2008	65	5/29/1956	18.38	27,600	6/7/2008	19.23	[8] 39,900	> 100	[3] 30,000		
03363500	Flatrock River at St. Paul, IN	303	764.84	1931-2008	78	1/5/1949	[11] 10.60	18,500	6/7/2008	12.82	16,400	10-25	[3] 24,400	1913 peak GH=20.5 ft	

03363900	Flatrock River at Columbus, IN	534	610.14	1968-2008	41	1/7/2005	16.45	22,400	6/7/2008	19.83	[8] 62,500	> 100	[3] 31,300		
03364000	East Fork White River at Columbus, IN	1,707	603.12	1949-2008	60	1/7/2005	17.05	57,300	6/8/2008	18.61	[8] 68,100	25-50	[3] 79,200	1913 peak GH=17.9 ft, Q=100,000 ft^3/s	
03364500	Clifty Creek at Hartsville, IN	91.4	677.34	1949-2008	60	1/21/1959	14.29	11,300	6/7/2008	17.85	[8] 17,600	> 100	[3] 14,300	1913 peak Q=20,000 ft^3/s	
03365500	East Fork White River at Seymour, IN	2,341	550.67	1928-2008	81	1/5/1949	19.67	78,500	6/8/2008	20.91	[8] 96,400	50-100	[3] 97,800	1913 peak Q=120,000 ft^3/s	
03371500	East Fork White River near Bedford, IN	3,861	473.59	1940-2008	69	1/9/2005	37.84	92,300	6/10/2008	34.41	67,100	10-25	[3] 108,000	1913 peak GH=47.5 ft (9.8 miles downstream at 469.2 ft datum), Q=155,000 ft^3/s	
03373500	East Fork White River at Shoals, IN	4,927	442.25	1904-2008	105	3/28/1913	42.20	160,000	6/12/2008	28.11	53,500	< 10	[3] 114,000		Moderate regulation at high flow by upstream reservoirs.
03374000	White River at Petersburg, IN	11,125	400	1929-2008	80	1/22/1937	28.30	183,000	6/12/2008	26.96	135,000	10-25	[3] 186,000	1913 peak GH=29.5 ft, Q=235,000 ft^3/s	Moderate regulation at high flow by upstream reservoirs
03377500	Wabash River at Mt. Carmel, IL	28,635	369.46	1928-2008	81	5/25/1943	[12] 27.54	305,000	6/14/2008	33.24	255,000	25-50	[3] 311,000	1913 peak GH=33.0 ft (at current datum), Q=428,000 ft^3/s	Moderate regulation at high flow by upstream reservoirs.

[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.

[2] 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 reciprocal of the recurrence interval is the annual exceedance probability, which is the probability that a given event magnitude will be exceeded or equaled in any given year. The exceedance probability for a recurrence interval of 10 years is 0.10; for 25 years, 0.04; for 50 years, 0.02; and for 100 years, 0.01.

[3] Coordinated discharge from the Indiana Department of Natural Resources, Division of Water publication entitled "Coordinated Discharges of Selected Streams in Indiana," accessed August 15, 2008, at http://www.in.gov/dnr/water/8726.htm.

[4] A higher maximum gage height occurred during a separate event: GH=11.21 ft on November 14, 1993.

[5] A higher maximum gage height occurred during a separate event: GH=25.06 ft on January 7, 2005.

[6] The historical peak flow for 03357000 White River at Spencer, IN, represents only the period 1926–1971, prior to when the station was converted to a stage-only site.

[7] The June 8, 2008, peak discharge for 03357000 White River at Spencer, IN, was determined by adjusting the 1971 stage-discharge relation on the basis of streamflow measurements made in 2008. For the purposes of this report, this peak flow is considered to be outside the period of systematic discharge record, and is therefore not identified as a new peak of record. This value does exceed the existing peak of record.

[8] New streamflow peak of record.

[9] Discharge determined by methods described in Interagency Advisory Committee on Water Data, Guidelines for Determining Flood Flow Frequency, Bulletin 17B (1982).

[10] A higher maximum gage height occurred during a separate event: GH=26.89 on January 8, 2005.

[11] A higher maximum gage height occurred during a separate event: GH=12.87 on January 6, 2005.

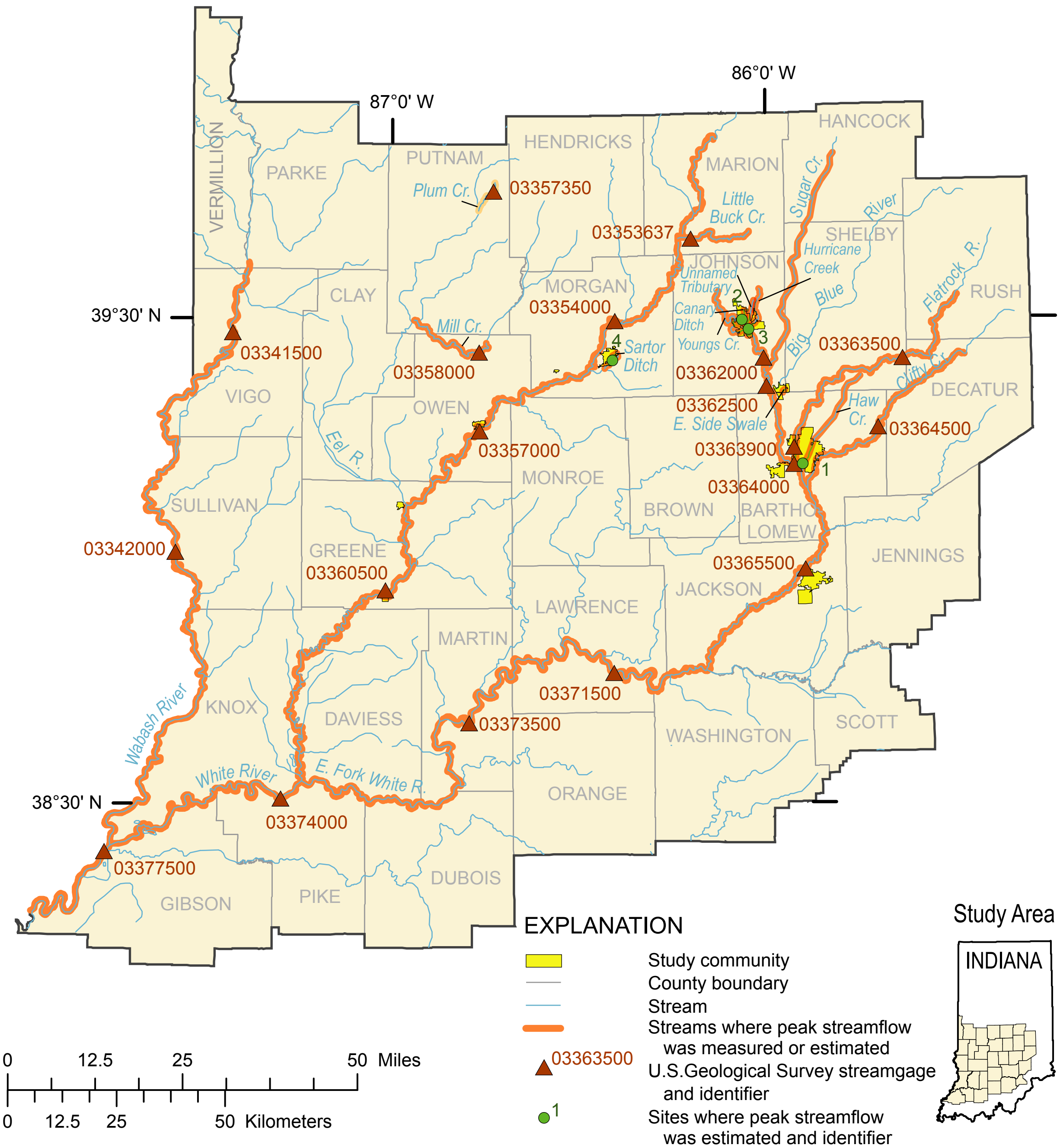

Figure 4. Locations of selected U.S. Geological Survey streamgages and ungaged sites (see tables 2 and 3 for flood-related data).

flows determined by indirect methods served as recent data points for rating-curve verification and extrapolation.

Indirect methods for determination of streamflow were required for rating extrapolation for the Flatrock River at Columbus streamgage, which is USGS station 03363900 (table 2), and for the determination of peak streamflow at four ungaged sites (table 3, fig. 4). Indirect determinations of streamflow make use of the energy and continuity equations for computing flow; specific forms of those equations differ for different types of flow, such as unobstructed open-channel flow and flow through culverts and bridge openings (Rantz and others, 1982). The data required for the computation of streamflow by indirect methods are obtained in a field survey that includes the elevation and location of high-water marks corresponding to the peak stage; cross sections of the channel along the reach; selection of roughness coefficients; and description of the geometry of structures such as culverts or bridges, depending on the method (Rantz and others, 1982).

The indirect methods used to estimate streamflow for this study were the contracted-opening method, culvert method, slope-area method, and step-**backwater** method. A general description of these methods can be found in Rantz and others (1982); detailed descriptions can be found in Bodhaine (1968), Dalrymple and Benson (1967), Davidian (1984), and Matthai (1967). Brief descriptions of the four methods follow:

- In the contracted-opening method, the abrupt drop in water-surface elevation between a bridge approach section and the contracted section under the bridge is used to compute flow.
- In the culvert method, the peak flow through a culvert can be determined from high-water marks that define the culvert headwater and tailwater elevations.
- In the slope-area method, flow is computed on the basis of a uniform-flow equation involving channel characteristics, water-surface profiles, and a roughness coefficient.
- In the step-backwater method, computer models are used to compute the water-surface elevation at a series of stream cross sections for a specific value of flow. Model input parameters include cross-section geometry, roughness coefficients, bridge-configuration data (bridge-opening geometry and roadway elevations) for modeled reaches with bridges, water-surface elevation at the most-downstream cross section, and streamflow. Streamflow is determined by inputting flow values iteratively until water-surface elevations at model cross sections match surveyed high-water-mark elevations.

If all flow was confined to a bridge or culvert, the contracted-opening method or culvert method was used; if flow was not confined to a bridge, the slope-area method or the step-backwater method was used. USGS software used included the Culvert Analysis Program (CAP) for the culvert method (Fulford, 1995), Slope Area Computation Program (SAC) for the slope-area method (Fulford, 1994), and the Water Surface Profile Program (WSPRO) for the step-backwater method (Shearman, 1989). For three sites, two different methods were used to estimate a peak-streamflow magnitude in an effort to improve the quality of the estimate. The methods used for each site were the contracted-opening and step-backwater methods for the Flatrock River at Columbus streamgage (table 2) rating extrapolation; the slope-area and step-backwater methods for the ungaged site Haw Creek near State Street, Columbus (table 3); the culvert method for the ungaged site Canary Ditch at U.S. Highway 31, Franklin (table 3); the step-backwater method for the ungaged site Hurricane Creek near mouth, Franklin (table 3); and the culvert and step-backwater methods for the ungaged site Sartor Ditch at south end of high school parking lot, Martinsville (table 3). Because many factors associated with the indirect computation of streamflow can have various levels of accuracy, and because the methods can depend considerably on engineering judgment, estimates may have large errors associated with them.

It was not possible to estimate peak streamflows associated with several streams in study communities; these included an unnamed tributary of Fall Creek in Paragon, an unnamed tributary of Youngs Creek in Franklin, and the Eel River in Worthington. Field surveys and the statements of local residents indicate that the flooding in Paragon appeared to be associated mostly with overland flow rather than an overflow from the unnamed tributary. The unnamed tributary of Youngs Creek in Franklin runs underground in a large box culvert; however, some of the flow from this tributary ran above ground level during the June 2008 flood and caused damage in the community. The flow dynamics of this situation were too complex to allow the estimation of streamflow. Potential backwater effects from the White River prevented the estimation of streamflow for Eel River in Worthington.

Estimation of Recurrence Intervals

Recurrence intervals associated with the peak streamflows for 19 active streamgages (table 2) and 3 ungaged locations (table 3) were estimated to indicate the relative magnitude of the June 2008 flooding. Recurrence intervals were obtained for 17 active streamgages and 3 ungaged locations from "coordinated" discharge-frequency curves available in the IDNR online publication "Coordinated Discharges of Selected Streams in Indiana" (*http://www.in.gov/dnr/water/8726.htm*). The coordinated discharge-frequency curves were established and are maintained according to a Memorandum of Understanding of May 6, 1976, signed by the U.S. Department of Agriculture, Soil Conservation Service (now the Natural Resources Conservation Service), the USGS, the U.S. Army Corps of Engineers, and the IDNR. These agencies mutually agreed to coordinate discharge-frequency values for use in water-resources investigations and planning activities in Indiana.

To estimate recurrence intervals for the streamgages Plum Creek near Bainbridge, USGS station 03357350 (table 2) and Mill Creek near Cataract, USGS station 03358000 (table 2) that are without coordinated discharge-frequency curves, the method (commonly called the "Bulletin 17B" method) described in Interagency Advisory Committee on Water Data (1982) was used. This method calculates recurrence intervals by fitting systematic annual peak discharge data to a log-Pearson type III distribution.

The recurrence interval could not be determined for the ungaged site Sartor Ditch at south end of high school parking lot, Martinsville (table 3). Recurrence-interval streamflows have not been established through the interagency coordination process, and regionalized regression equations and selected basin characteristics could not be used to estimate recurrence interval streamflows (basin characteristics for Sartor Ditch were beyond the range used for development of regression equations).

Table 3. Estimated peak streamflows and estimated recurrence intervals during the flood of June 7–9, 2008, at selected ungaged locations in Indiana. (Locations of sites 1-4 are shown on figure 4.)

[mi^2, square miles; ft^3/s, cubic feet per second; <, less than; >, greater than]

Site number	Stream and location	County	Drainage area at site (mi^2)	Peak flow (ft^3/s) for given recurrence interval				Estimated peak flow during June 2008 flood		
				[1] 10-year	25-year	50-year	100-year	Estimated peak flow (ft^3/s)	Recurrence interval (years)	Comment
1	Haw Creek near State Street, Columbus	Bartholomew	55.7	[2] 4,690	[2] 6,210	[2] 7,380	[2] 8,430	[3] 13,900	> 100	Peak flow 65% greater than 100-year flood
2	Canary Ditch at US Highway 31, Franklin	Johnson	5.39	[2] 1,410	[2] 1,750	[2] 2,100	[2] 2,370	[3] 1,600	10-25	
3	Hurricane Creek near mouth, Franklin	Johnson	16.4	[2] 2,500	[2] 3,100	[2] 3,700	[2] 4,200	[3] 3,860	50-100	
4	Sartor Ditch at south end of high school parking lot, Martinsville	Morgan	1.66	[4] Undetermined	Undetermined	Undetermined	Undetermined	860	Undetermined	

[1] 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 reciprocal of the recurrence interval is the annual exceedance probability, which is the probability that a given event magnitude will be exceeded or equaled in any given year. The exceedance probability for a recurrence interval of 10 years is 0.10; for 25 years, 0.04; for 50 years, 0.02; and for 100 years, 0.01.

[2] Coordinated discharge from the Indiana Department of Natural Resources, Division of Water publication "Coordinated Discharges of Selected Streams in Indiana, accessed August 15, 2008 at http://www.in.gov/dnr/water/8726.htm.

[3] Peak streamflow estimated by indirect measurement methods.

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

Estimated Magnitudes and Recurrence Intervals of Peak Streamflows for the Flood of June 7–9, 2008

Peak-gage-height data, peak-streamflow data, and estimated recurrence intervals from the June flood for 19 USGS streamgages in central and southern Indiana are listed in table 2, and streamgage locations are shown in figure 4. New streamflow peaks of record were set at 7 of the 19 streamgages. For the 19 streamgages, estimated recurrence intervals were greater than 100 years at 5 streamgages, 50–100 years at 2 streamgages, 25–50 years at 4 streamgages, 10-25 years at 4 streamgages, and less than 10 years at 4 streamgages. Peak-streamflow data from the June flood for four ungaged locations in central and southern Indiana and estimated recurrence intervals for three ungaged locations are listed in table 3, and site locations are shown in figure 4. The estimated recurrence interval was greater than 100 years at Haw Creek near State Street, Columbus; 50–100 years at Hurricane Creek near Mouth, Franklin; and 10–25 years at Canary Ditch at U.S. Highway 31, Franklin. An estimated recurrence interval could not be determined for Sartor Ditch at south end of high school parking lot, Martinsville.

Flood-Peak Inundation Maps

Flood-peak inundation maps were produced for 17 stream reaches in the study area (fig. 1) by use of geographic information system (GIS) software and programs. High-water-mark elevations (NAVD 88) and locations (latitude-longitude) were used in conjunction with GIS land-surface elevation data files termed digital elevation models (DEMs) to develop the maps. For study reaches that had a streamgage, the peak-gage height recorded by the streamgage also was used to develop the maps. The White River at Newberry map was developed from the peak-gage height recorded at the White River at Newberry streamgage (table 2, fig. 4) and not from high-water marks. GIS Arc Macro Language (AML) programs were written to produce a plane representing the flood-peak water surface that was fit through the high-water marks and that sloped in the direction of water flow. The program duplicated the high-water-mark elevation data points across the **flood plain** perpendicular to the direction of the flood flow. Elevations between high-water marks are proportional interpolations of the high-water-mark data and are positioned to generate a flood surface sloping with the water flow. A TIN (triangular irregular network) surface was usually fit through the data points because TIN-generated surfaces pass exactly through the data-point elevations. After the flood surface was generated, a flood depth map was made by subtracting the DEM from the flood surface. The flood-peak inundation maps were produced in a GIS file format that provides peak flood extent and depth. This format allows the maps to be overlain upon other maps and aerial photographs, and to be imported into various GIS applications, such as FEMA's HAZUS-MH (Federal Emergency Management Agency, 2008) program to estimate flood damages. An inundation map was not produced for Sartor Ditch in Martinsville because the DEM was not adequate to produce accurate mapping. An inundation map produced for the community of Elnora was reviewed by IDNR personnel and was found to contain inaccuracies associated with complex flow regimes caused by levee breaks; thus, the map is not included in this report. Selected flood-map illustrations created from the peak flood extent and depth GIS files and from aerial photographs are shown in Appendix 2.

Flood-Peak Profiles

The AML programs used to produce flood-peak maps were further developed to also generate flood-peak profile plots. Flood profiles were produced for 15 streams in the study area (Appendix 3). The profiles were produced by plotting high-water-mark elevations (NAVD 88) by mile of stream as measured upstream from the mouth of the stream. 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; the actual water surface may have substantially departed from the water surface depicted in the profiles in some locations. For example, it is common for the water surface to drop between the upstream and downstream face of a bridge or culvert; potential water-surface elevation drops may not be reflected in the profiles. Locations of street crossings over the streams were added to the plots in another software package. The river-mile location of the street crossings was calculated by GIS-based programs. There was not sufficient high-water mark data to produce profile plots for the Blue River at Edinburgh, White River at Martinsville, and White River at Newberry reaches. A profile was not created for the unnamed tributary of Fall Creek at Paragon because most of the flooding in Paragon appeared to be associated with overland flow rather than an overflow from the unnamed tributary.

Description of Flood Damages and Impacts

The immediate impact of the heavy rainfall of June 6–7 was widespread flash flooding. The Paragon, Spencer, Franklin, and Martinsville areas all had extensive flooding early on June 7 (Shipe, 2008) as small streams such as Sartor Ditch in Martinsville rose rapidly. Later in the afternoon and into the evening of June 7, extensive flooding occurred in the Edinburgh and Columbus areas as larger streams such as Haw Creek, Youngs Creek, and Sugar Creek rose rapidly and peaked. The East Fork White River at Columbus rose from lowland flooding to a near-record peak stage within 6 hours on June 7 (Shipe, 2008). Early on June 8, flash flooding and flooding on small to medium-sized streams had dissipated, but extensive flooding of the White and East Fork White Rivers occurred in the Spencer, Seymour, Worthington, and Newberry areas (Shipe, 2008). Flood crests continued to travel downstream on the White, East Fork White, and Wabash Rivers on June 8 and 9; but because little rain had fallen in southern Indiana and southern Illinois, these flood crests dissipated as they moved downstream.

Communities that were extensively flooded included Martinsville, Franklin, Paragon, Spencer, and Columbus. Residences and businesses in these communities received extensive damage. Most of the town of Paragon and nearly half of Martinsville were inundated by floodwaters (Shipe, 2008). In Franklin, the Johnson County Hospital and several local government office buildings flooded.

The hardest hit community was Columbus, which became isolated because nearly all roads into the city were flooded. About 15 percent of all structures in the city were flooded (Shipe, 2008). The first floor and basement of the Columbus Regional Hospital was flooded by Haw Creek, causing the evacuation of 157 patients and $125 million in damage (Indiana NewsCenter, 2008). More than 70 businesses in Columbus received flood damage (Indianapolis Star, 2008), including $100 million in damage to a research and development center for a diesel engine manufacturer (Insurance Journal, 2008).

The following is a summary of flood impacts compiled as of August 31, 2008.

- The flooding caused three fatalities and five injuries.
- More than 8,400 evacuations and water rescues were made during the flooding (National Weather Service, 2008).
- Approximately 1,300 National Guard members (National Guard, 2008), 350 Red Cross staff, 75 State Troopers, and 140 U.S. Marines were mobilized to help flood victims (Indianapolis Star, 2008). The Indiana Salvation Army set up three feeding sites, eight mobile feeding units, and one shelter, providing more than 5,000 meals and 10,000 bottles of water and sports drinks; FEMA set up 15 regional offices and sent about 140,000 bottles of water to Indiana (Indianapolis Star, 2008).
- More than 5,600 residential dwellings were damaged in the counties included in the Presidential Disaster Declaration (Indiana Office of Disaster Recovery, 2008).
- Transportation impacts were numerous and widespread. Temporary interstate closures included I–70 near Cloverdale and I–65 near Edinburgh (Shipe, 2008). Many state and local roads were closed; for example, the entire transportation network in the White River flood plain in Greene County was closed (Shipe, 2008).
- Damage to infrastructure included more than 650 roads, more than 60 bridges, approximately 100 culverts, more than 100 dams and levees, and 56 water-supply or wastewater-treatment facilities (Indiana Office of Disaster Recovery, 2008). There was a major dam break at Princes Lake in Johnson County that forced the evacuation of about 100 persons, and levee breaks affected large areas of agricultural lands in Daviess and Greene Counties (Indianapolis Star, 2008).
- Agricultural impacts were major: an estimated 7 percent of Indiana's total soybean, corn, and wheat acres were flooded, and an estimated 1.4 million acres of Indiana farmland needed repair or rehabilitation (Indiana Office of Disaster Recovery, 2008).
- Requests to FEMA for Public Assistance have included 243 from local units of government, 39 from nonprofit groups, and 23 from units of State Government; there have been more than 16,300 requests for Individual Assistance (Indiana Office of Disaster Recovery, 2008).

By August 31, 2008, $117.3 million in disaster assistance had been approved by FEMA or the U.S. Small Business Administration for Indiana residences and businesses (Indiana Office of Disaster Recovery, 2008). Damages to the Columbus Regional Hospital and the diesel engine facility totaled in excess of $200 million. The damage to agricultural lands (funds needed for repair or rehabilitation of crop-producing acreage) was estimated to be $200 million (Indiana Office of Disaster Recovery, 2008). There are many other costs associated with the floods not yet tallied, such as damage to public and private infrastructure and damage to personal property, such as automobiles. Total damage costs resulting from the June flooding are expected to be the highest of any disaster in the history of Indiana (National Climatic Data Center, 2008).

Summary

Heavy rains caused severe flooding on June 7–9, 2008, and caused hundreds of millions of dollars worth of damage to homes, businesses, infrastructure, and agricultural lands in central and southern Indiana. Three deaths were attributed to the flooding, and thousands of persons were evacuated from flooded areas.

Estimated rainfall totals of 2 to more than 10 in. fell June 6–7 upon saturated soils and added to already above-normal streamflows. Average recurrence intervals of total rainfall amounts for a 24-hour duration ranged from greater than 50 years to greater than 1,000 years at five NWS precipitation stations. Given the severity of the June 2008 flooding in Indiana, the USGS, in cooperation with the FEMA and the IDNR, Division of Water, did a study to document the meteorological and hydrological conditions leading to the flood; compile flood-peak gage heights, streamflows, and recurrence intervals at USGS streamgages and at selected ungaged locations; construct flood profiles and peak-gage-height inundation maps; and summarize flood damages and impacts.

The IDNR and the USGS set and surveyed high-water marks to obtain peak water-surface elevations for about 50 mi of streams. Peak gage heights were obtained either from electronic data recorders or from surveyed high-water marks at 19 USGS streamgages. Peak streamflow for the streamgages was tabulated by use of the rating curve developed for that streamgage. Indirect methods were used to estimate peak streamflow at ungaged locations on four streams and to extrapolate the rating curve at the USGS streamgage on the Flatrock River at Columbus. New streamflow peaks of record occurred at nine streamgages. Estimated recurrence intervals of greater than 100 years occurred at five USGS streamages and one ungaged location. Estimated recurrence intervals of 50–100 years occurred at two streamgages and one ungaged location. Estimated recurrence intervals for 13 other streamgages and 2 ungaged sites ranged from less than 10 years to 25–50 years.

Surveyed high-water-mark data and ground-elevation data were used to produce flood-peak inundation maps for 17 stream reaches and were used to produce flood-peak profiles for 15 stream reaches.

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Glossary

The following definitions, except where 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. For example, the annual exceedance probability of the 100-year peak flood streamflow is 0.01. In other words, there is a 1-percent chance that the 100-year peak flow will be exceeded or equaled in any given year.

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 since 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 highwater, but a fossil flood plain if it is beyond the reach of the highest flood.

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.

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 gage.

recurrence interval (return period) The average interval of time within which the given flood will be equaled or exceeded once.

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.

Appendix 1. Site Descriptions and High-Water Marks at Study Sites, Flood of June 7–9, 2008, Indiana (separate document)

Appendix 2. Flood-Peak Inundation Maps for Selected Communities, Flood of June 7–9, 2008, Indiana (separate document)

Appendix 3. Flood-Peak Elevation Profiles for Selected Sites, Flood of June 7–9, 2008, Indiana (separate document)

Morlock and others—**Flood of June 7–9, 2008, in Central and Southern Indiana**—Open-File Report 2008–1322