Prepared in cooperation with the Federal Emergency Management Agency

High-Water Marks from Tropical Storm Irene for Selected River Reaches in Northwestern Massachusetts, August 2011

Data Series 775

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

Front cover. Photographs of Deerfield River at dam #3 at Shelburne Falls, Massachusetts. Top left photograph was taken on May 14, 2012, during near-normal flows. The rocky area below the dam is called the Glacial Potholes. The bottom right photograph was taken on August 28, 2011, during flood flows from tropical storm Irene. Photographs by John E. Robison, Amherst, Massachusetts.

Back cover. Photograph of Deerfield River at the Bridge Street bridge (left) and the Bridge of Flowers (right) at Shelburne Falls, Massachusetts, taken on August 28, 2011, during flood flows from tropical storm Irene. Photograph by John E. Robison, Amherst, Massachusetts.

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By Gardner C. Bent, Laura Medalie, and Martha G. Nielsen

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U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2013

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Conversion Factors, Datum, and Abbreviations

Inch/Pound to SI

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

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

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

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

Abbreviations

FEMA	Federal Emergency Management Agency
GPS	Global Positioning System
HWM	High-water mark
NGS	National Geodetic Survey
USGS	U.S. Geological Survey

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Abstract

A Presidential Disaster Declaration was issued for Massachusetts, with a focus on the northwestern counties, following flooding from tropical storm Irene on August 28–29, 2011. Three to 10 inches of rain fell during the storm on soils that were susceptible to flash flooding because of wet antecedent conditions. The gage height at one U.S. Geological Survey (USGS) streamgage rose nearly 20 feet in less than 4 hours because of the combination of saturated soils and intense rainfall. Eight of 16 USGS long-term streamgages in western Massachusetts set new peaks of record on August 28 or 29, 2011.

To document the historic water levels of the streamflows from tropical storm Irene, the USGS identified, flagged, and surveyed 323 high-water marks in the Deerfield and Hudson-Hoosic River basins in northwestern Massachusetts. Areas targeted for high-water marks were generally upstream and downstream from structures along selected river reaches. Elevations from high-water marks can be used to confirm peak river stages or help compute peak streamflows, to calibrate hydraulic models, or to update flood-inundation and recovery maps. For areas in western Massachusetts that flooded as a result of tropical storm Irene, high-water marks surveyed for this study have helped to confirm or determine instantaneous peak river gage heights at several USGS streamgages.

Introduction

The 3 to 10 inches of rainfall from tropical storm Irene resulted in historic rainfall and flooding on August 28–29, 2011, in western Massachusetts. On the basis of preliminary damage assessments, President Obama declared a major disaster in the Commonwealth of Massachusetts on September 3, 2011, with individual and public assistance available for Berkshire and Franklin Counties (Federal Emergency Management Agency, 2013). On October 20, 2011, the Presidential Disaster Declaration (FEMA-4028-DR) also designated Hampden and Hampshire Counties in western Massachusetts (plus five other counties in eastern Massachusetts) as eligible for public assistance (Federal Emergency Management Agency, 2013). As of February 2013, Federal financial assistance to Massachusetts for recovery from tropical storm Irene allotted more than $11 million for individual assistance and more than $53 million for public assistance (Federal Emergency Management Agency, 2013).

In response to the Presidential Disaster Declaration for Massachusetts resulting from tropical storm Irene (DR-4028), a Federal Emergency Management Agency (FEMA) Mission Assignment was authorized for the U.S. Geological Survey (USGS) to identify and flag high-water marks (HWMs) in northwestern Massachusetts, specifically along river reaches in the Deerfield and Hudson-Hoosic River Basins and to survey their elevations. An April 2012 Interagency Agreement between FEMA Region I (New England) and USGS authorized the surveying of HWM elevations to the North American Vertical Datum of 1988 (NAVD 88) for selected river reaches in northwestern Massachusetts as a result of tropical storm Irene.

Purpose and Scope

The purpose of this report is to document and provide data on HWMs from tropical storm Irene on August 28–29, 2011, for selected river reaches in the Deerfield and Hudson-Hoosic River Basins in northwestern Massachusetts. Methods used to identify, flag, and survey HWMs to vertical and horizontal datums are described. This report also presents a summary of gage heights and peak streamflows, in some instances verified by HWMs, resulting from tropical storm Irene at USGS streamgages throughout western Massachusetts.

Study Area

HWMs were identified in the Deerfield and Hudson-Hoosic River Basins in northwestern Massachusetts (fig. 1). Elevations in northwestern Massachusetts range from Mount Greylock at 3,487 feet (ft) to the mouth of the Deerfield River at about 120 ft above sea level (NGVD 88). Western

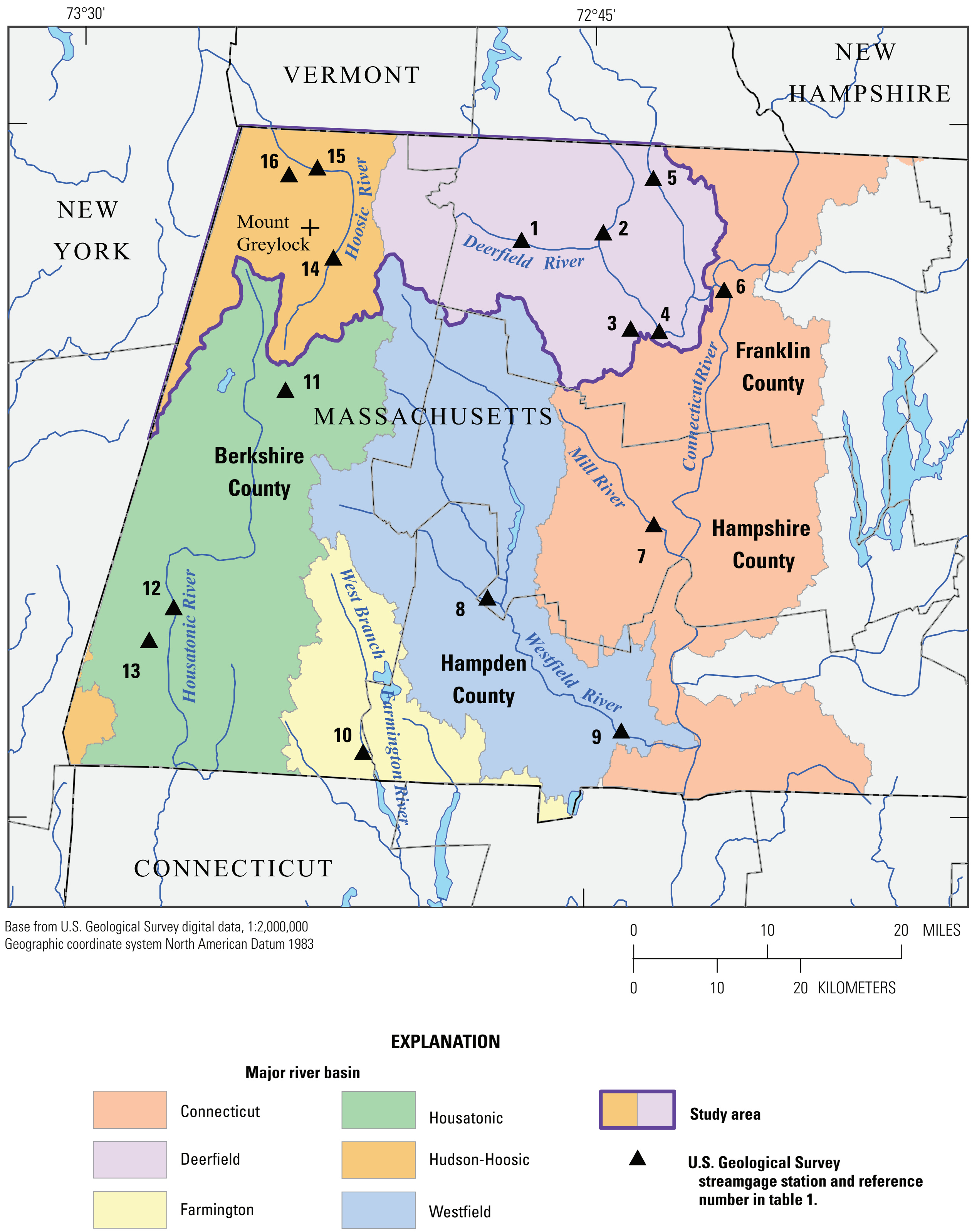


Figure 1. Locations of U.S. Geological Survey streamgages with at least 25 years of record in western Massachusetts.

Massachusetts is fairly rural with most of the population living in the valleys of the major river basins. The Deerfield River has a drainage area of 665 square miles (mi^2) in Vermont and Massachusetts (347 mi^2 in Massachusetts), has multiple hydroelectric facilities, and is a popular fishing destination for native and stocked trout (Deerfield River Watershed Association, 2005). The Hudson-Hoosic River Basin in Massachusetts covers about 240 mi^2 and sustains native wild trout (Commonwealth of Massachusetts, 2013). The largest tributary drainage area of the Hudson River in Massachusetts is that of the Hoosic River, which originates in western Massachusetts and flows north and west through Vermont and into New York State.

Tropical Storm Irene

After leaving a wake of destruction through the Caribbean, eastern North Carolina, and eastern New Jersey, Irene made landfall east of New York City as a tropical storm and then moved northeast over northwestern Connecticut and into western Massachusetts before continuing northeast to Vermont (Fanelli and Fanelli, 2011) (fig. 2). The highest observed rainfall totals from Irene in western Massachusetts were 9.92 inches (in.) in Conway and 9.75 in. in Ashfield (National Weather Service, 2011). The Northeast Regional Climate Center ranked August 2011, with an average rainfall for Massachusetts of 10.05 in., as the second wettest August in 117 years of precipitation records for Massachusetts; the wettest year was 1955 with 13.52 in. of rainfall (Northeast Regional Climate Center, 2011). Precipitation in western Massachusetts during August 2011 was 11.21 in., more than 3 times higher than the average August precipitation (3.41 in.) (Massachusetts Department of Conservation and Recreation, 2011). During August 2011 before the arrival of tropical storm Irene, western Massachusetts already had saturated soils from abundant rainfall, resulting in conditions susceptible to flash flooding (Northeast Regional Climate Center, 2011).

Peak gage heights and streamflows from tropical storm Irene were recorded at 16 long-term (25 or more years of record) USGS streamgages in western Massachusetts on August 28 or 29, 2011 (fig. 1 and table 1). Most of the streamgages reached peak gage heights within about 20 hours of the start of the rainfall, similar to USGS 01332500 Hoosic River near Williamstown, Mass. (fig. 3A). Some streamgages reached a peak gage height in about 4 hours; for example, the gage height at USGS 01170000 Deerfield River near West Deerfield, Mass. (reference number 4 on fig. 1), increased from about 5 ft to nearly 24 ft in less than 4 hours (fig. 3B). This rapid response resulted from wet antecedent soil conditions and very intense rainfall. Eight of 16 USGS streamgages in western Massachusetts with long-term records (ranging from 27 to 108 years) set new records for peak streamflows (U.S. Geological Survey, 2013) during tropical storm Irene (table 1).

High-Water Marks

HWMs are the evidence of the highest water levels during a flood (Benson and Dalrymple, 1967). Bits of material, such as seeds, tree needles, grass, leaves, woody debris, trash, or sediment, that are transported by floodwaters sometimes remain on tree bark, buildings, or fences at the highest water level, leaving a trail to document the height of water (fig. 4). Scour lines in streambanks generally are less accurate and more variable than HWMs from debris or stains. The most useful HWMs tend to result from water that was moving at a low velocity with minimal wave action, usually at some distance from the main river channel or water body. Optimally, HWMs are identified immediately following peak flood levels because over time, rain, wind, and sun can wash, blow, or fade away the HWM material that depict the peak. The general methods used to identify and document HWMs are described by Benson and Dalrymple (1967).

The Deerfield and Hudson-Hoosic River Basins in northwestern Massachusetts, identified by FEMA as having more flood damage from tropical storm Irene than other areas of western Massachusetts, were the focus of this effort to document HWMs. From August 31 through September 30, 2011, the USGS identified and flagged 323 HWMs in those two river basins (fig. 5 and appendix 1). In the Deerfield River Basin, 260 HWMs were flagged at 104 locations on 12 different stream reaches. In the Hudson-Hoosic River Basin, 63 HWMs were flagged at 30 locations on 3 different stream reaches. Of the 323 HWMs that were flagged, 318 were surveyed directly, and 5 were surveyed by an estimated method (described in the section “Surveying”).

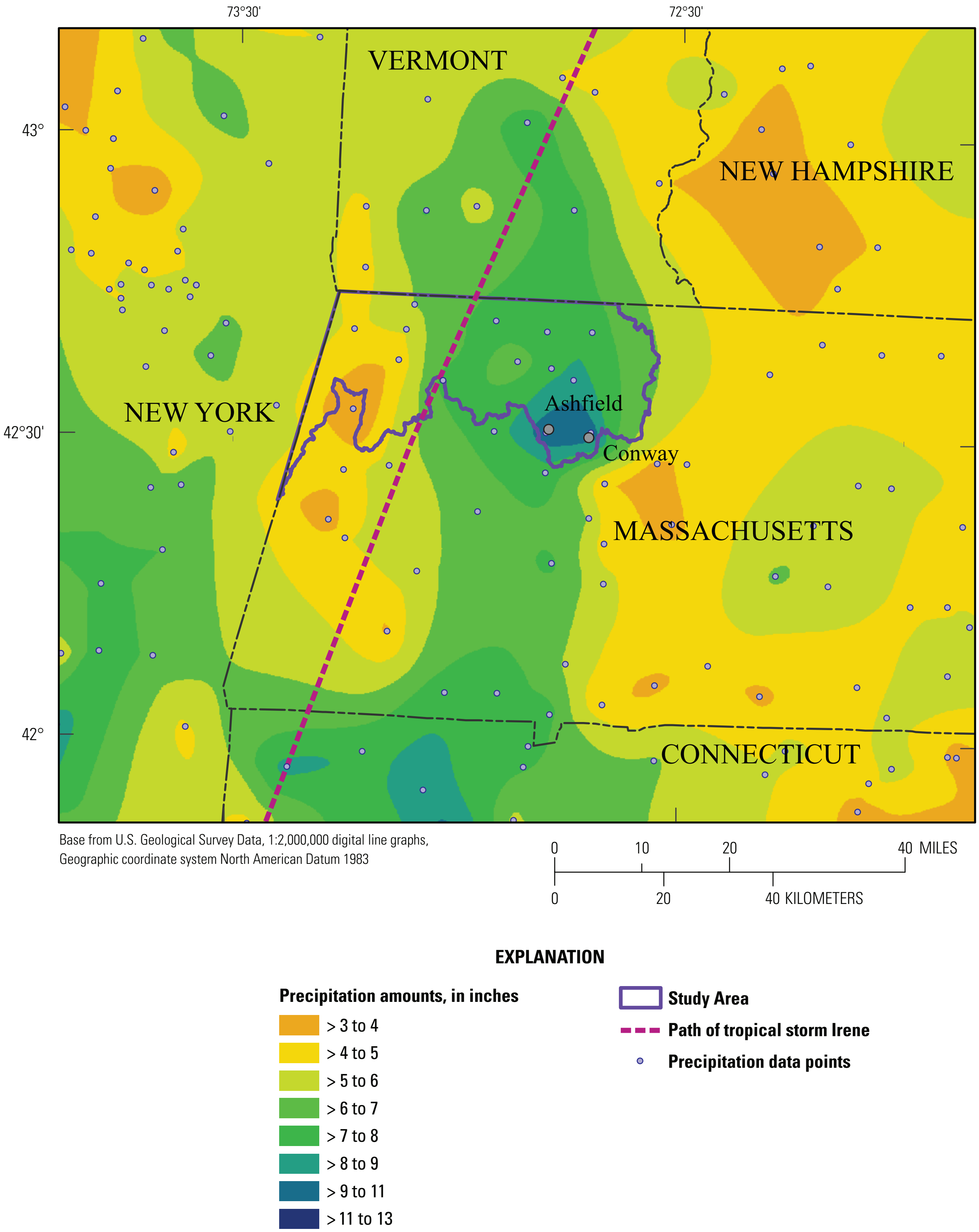


Figure 2. Distribution of rainfall and path of tropical storm Irene across western Massachusetts on August 28–29, 2011. Information on the precipitation data points and the path of tropical storm Irene is from the National Oceanic and Atmospheric Administration (2011a and b). (>, greater than)

Table 1. Peak streamflows and gage heights compared to historical peaks for U.S. Geological Survey streamgages in western Massachusetts, August 28–29, 2011.

[Source of peak streamflow data is U.S. Geological Survey (USGS), 2013; mi², square miles; ft, feet; ft³/s, cubic feet per second; --, data are not available]

Reference number for figure 1	USGS station number	USGS station name	Drainage area (mi²)	August 2011 peak streamflow (bold indicates new peak of record)				Historical peak streamflow			
				Date	Gage height (ft)	Streamflow (ft³/s)	Time to peak from base flow (hours)	Date	Gage height (ft)	Streamflow (ft³/s)	Number of years of record
			Deerfield River Basin								
1	01168500	Deerfield River at Charlemont, Mass.	361	8/28/2011	20.17[a]	54,000	--	9/21/1938	20.17	56,300	98
2	01169000	North River at Shattuckville, Mass.	89	8/28/2011	17.99	**56,100**	12	10/9/2005	12.32	18,800	72
3	01169900	South River near Conway, Mass.	24	8/28/2011	14.27	**13,000**	15	10/9/2005	11.90	8,770	45
4	01170000	Deerfield River near West Deerfield, Mass.	557	8/28/2011	23.77	**103,000**	18	4/5/1987	17.71	61,700	71
5	01170100	Green River near Colrain, Mass.	41	8/28/2011	13.98	**19,400**	9	10/9/2005	9.14	6,540	44
			Connecticut River Basin								
6	01170500	Connecticut River at Montague City, Mass.	7,860	8/28/2011	35.91	127,000	16	3/19/1936	49.20	236,000	108
7	01171500	Mill River at Northampton, Mass.	53	8/28/2011	16.42[b]	**7,020**	13	8/19/1955	11.78	6,300	73
			Westfield River Basin								
8	01181000	West Branch Westfield River at Huntington, Mass.	94	8/28/2011	16.78	**32,400**	--	8/19/1955	15.27	26,100	76
9	01183500	Westfield River near Westfield, Mass.	497	8/28/2011	19.92	26,200	15	8/19/1955	34.20	70,300	97
			Farmington River Basin								
10	01185500	West Branch Farmington River near New Boston, Mass.	92	8/28/2011	11.50	17,300	12	8/19/1955	14.06	34,300	98
			Housatonic River Basin								
11	01197000	East Branch Housatonic River at Coltsville, Mass.	58	8/28/2011	8.20[c]	**6,410**	19	9/21/1938	10.80	6,400	76
12	01197500	Housatonic River near Great Barrington, Mass.	282	8/29/2011	9.62[d]	6,780[d]	29	1/1/1949	12.08	12,200	98
13	01198000	Green River near Great Barrington, Mass.	51	8/28/2011	12.46	**7,550**	17	7/13/1996	9.84	6,740	27[e]
			Hudson-Hoosic River Basin								
14	01331500	Hoosic River at Adams, Mass.	47	8/28/2011	9.50[b]	2,690	15	9/21/1938	8.25	5,080	80
15	01332500	Hoosic River near Williamstown, Mass.	126	8/28/2011	14.58	**14,900**	14	12/31/1948	14.85	13,000	71
16	01333000	Green River at Williamstown, Mass.	43	8/28/2011	6.67	**4,140**	--	12/21/1973	5.68	4,060	62

[a]The rating curve (relation between gage height and streamflow) has changed between 1938 and 2011; thus, the same gage height (20.17 ft) for the peaks in 2011 and 1938 produces different streamflows.

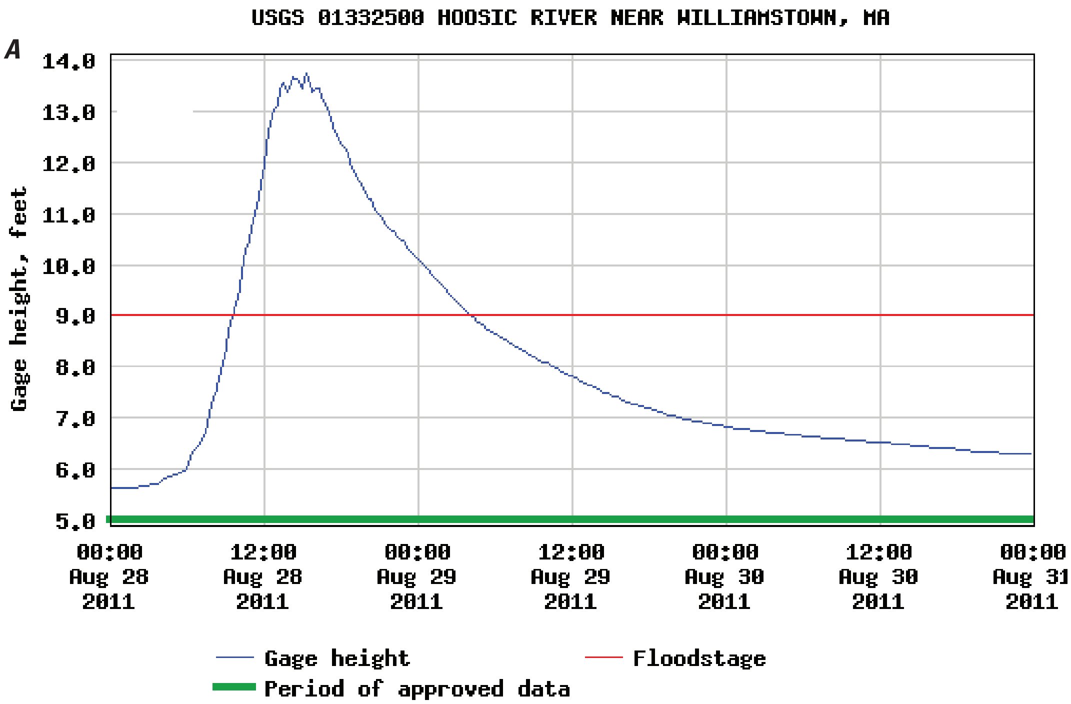
[b]Gage height is higher than the historical peak gage height due to a change in the gage datum.

[c]Gage height is lower than the historical peak gage height due to a change in the gage datum.

[d]Peak streamflow of water year 2011 occurred on a different date.

[e]Record of streamflow is not continuous.

A



B

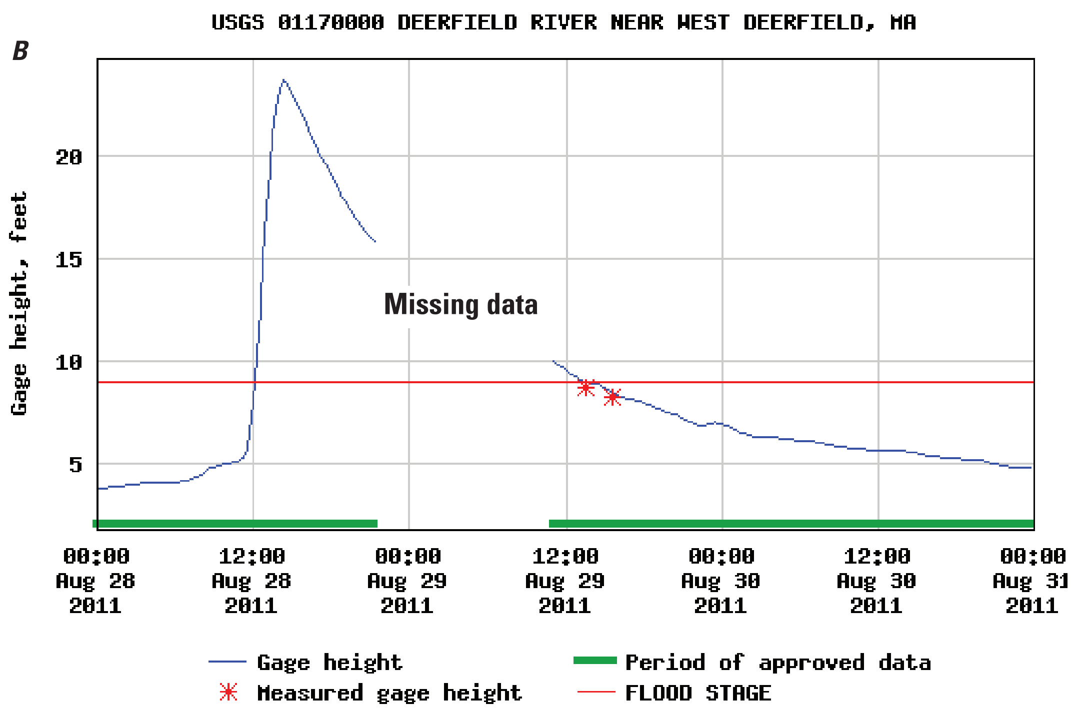


Figure 3. Hydrographs for U.S. Geological Survey streamgages *A,* Hoosic River near Williamstown (station 01332500) and *B,* Deerfield River near West Deerfield (station 01170000) in Massachusetts, showing a rapid rise in gage height due to tropical storm Irene, August 28–29, 2011. About 14 hours of data are missing in the station 01170000 hydrograph due to equipment malfunction.

A. HWM-MA-EBNORTH-160

C. HWM-MA-HOOSIC-276

B. HWM-MA-GREEN-079

D. HWM-MA-CHICKLEY-225

E. HWM-MA-EBNORTH-157

Figure 4. Examples of high-water marks associated with flooding from tropical storm Irene in the Deerfield and Hudson-Hoosic River Basins in northwestern Massachusetts, August 28–29, 2011: *A, B,* mud and debris line on buildings; *C,* debris on the ground; *D,* wash line on the ground; and *E,* debris on tree.

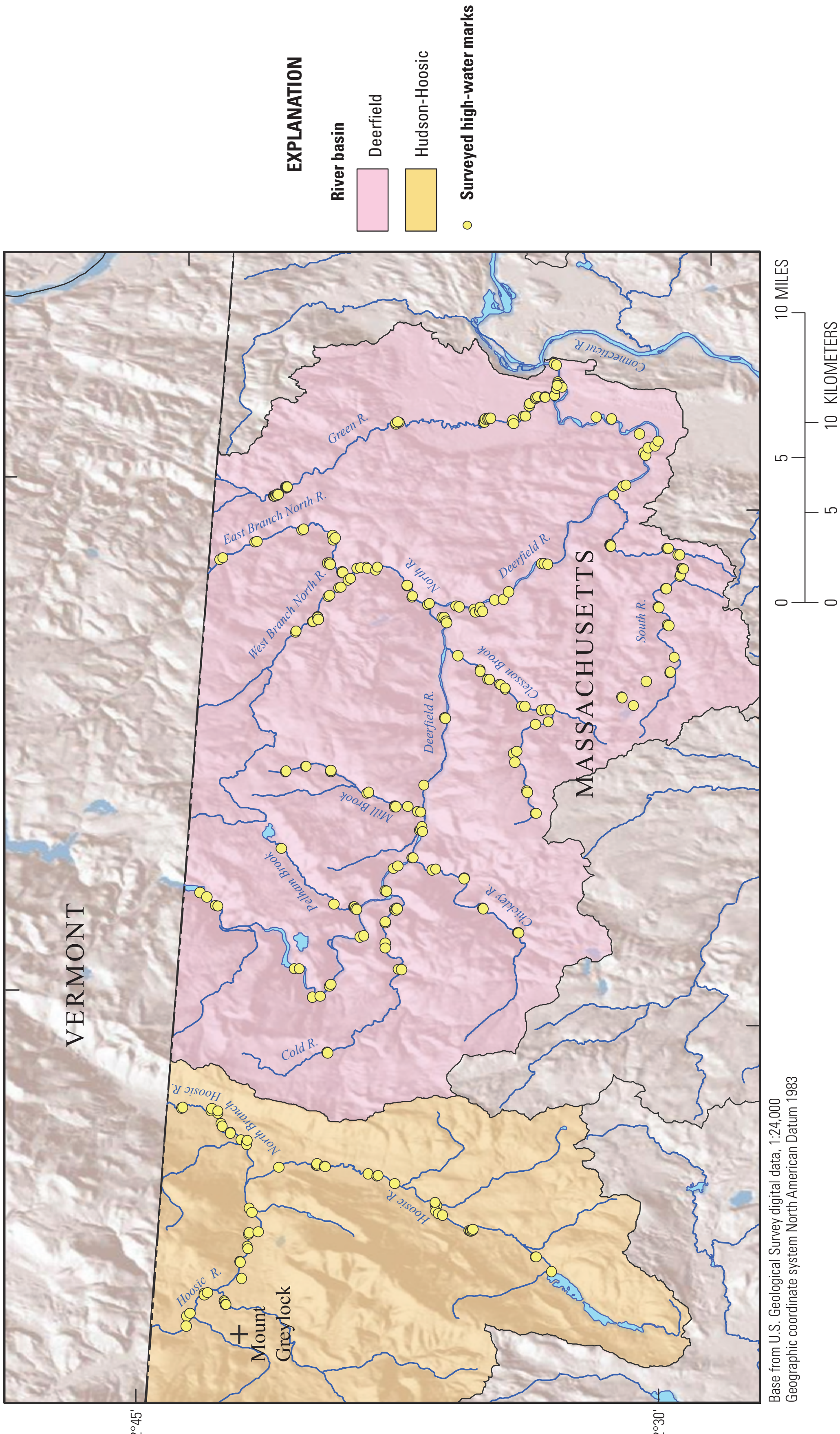


Figure 5. Locations of surveyed high-water marks from flooding due to tropical storm Irene in the Deerfield and Hudson-Hoosic River Basins in northwestern Massachusetts, August 28–29, 2011.

Identification and Flagging

USGS field personnel working in pairs identified and flagged HWMs at locations upstream and downstream from structures along the largest stream reaches within the Deerfield and Hudson-Hoosic River Basins. Targeted structures included bridges for State, city, or town roads, trains, driveways, or pedestrians; dams; wastewater-treatment and other infrastructure facilities; and USGS streamgages. At each structure, attempts were made to find at least one upstream and one downstream HWM whose quality could be characterized as “good” or “excellent” according to a quantitative accuracy scale (table 2; modified from Lumia and others, 1987). For each HWM, a durable identification mark was made using a USGS HWM disk, stake, chisel mark, or permanent pen (fig. 4). Survey flagging was placed at each HWM location to facilitate the ability of survey crews to find the location at a later date. Information recorded on field forms for each HWM included a physical description of the HWM, horizontal location by latitude and longitude using measurements from a handheld Global Positioning System (GPS), rating of general accuracy (Lumia and others, 1987), description of the durable identification mark left by the USGS crew, and directions for survey crews to find the HWM. Photographs of the HWMs and the surrounding area were taken as part of the documentation[1] and to help future survey crews find the marks.

Table 2. Quantitative scale to rate accuracy of high-water marks (modified from Lumia and others, 1987).

[±, plus or minus; >, greater than]

Rating	Accuracy, in feet
Excellent	±0.02
Good	±0.05
Fair	±0.10
Poor	±0.20
Very poor	> ±0.20

Surveying

Elevations of most of the HWMs that had been identified and flagged during August and September 2011 were surveyed from June through August 2012 to NAVD 88 using the Global Navigation Satellite System, survey grade GPS receivers, and total station surveying equipment. Surveying methods followed those described by Rydlund and Densmore (2012). Eleven of the HWMs flagged during August and September 2011 were surveyed during April and May 2013. Five of the original 323 HWMs could not be found (HWM-MA-CLESSON-202, HWM-MA-DEERFIELD-031, HWM-MA-GREEN-092, HWM-MA-GREEN-093, and HWM-MA-WBNORTH-175 in appendix 1) because either the HWM had been removed or the elevation had clearly changed. The elevations for these five HWMs were estimated by surveying at the ground elevation that was described when the site was flagged in August and September 2011 and adding the distance from the ground to the HWM, as measured by tape and recorded in the field notes. GPS surveys were conducted using Trimble® R8 GPS system receivers. If the HWM itself could not be physically accessed for the survey, other options were to (1) survey a point directly above or below the HWM and measure the elevation difference to the HWM with a tape measure or (2) survey a surrogate point nearby and use a total station to measure the elevation difference. The GPS receiver was reinitialized (flipped upside down for several seconds or rotated 180 degrees to lose the GPS signals) several times at each point to obtain multiple independent readings. If the vertical elevations of the multiple readings differed by more than about 0.10 ft, additional readings were taken until the differences were less than 0.10 ft. In most cases, agreement within 0.05 ft was reached.

Continuous real-time differential corrections to the GPS horizontal and vertical positions were made using a proprietary fixed-base station GPS network of receivers operated by KeyNetGPS, Inc. (2013). The fixed-base station GPS network of receivers and associated software determined corrections for satellite signals received by the field GPS receiver for ionosphere and other atmospheric disturbances. The fixed-base station GPS network of receivers continuously streamed data to a central server that calculated corrections in real time to the field GPS receiver. The five fixed-base station GPS receivers closest to the western Massachusetts survey area (HAMP in western Massachusetts, NYAB and NYHS in eastern New York, and VTBE and VTD2 in southern Vermont) composed the network that was utilized for these corrections (KeyNetGPS, Inc., 2013).

Checks on the accuracy of the GPS measurements were made by comparing instrument readings from two types of survey equipment at 10 National Geodetic Survey (NGS) benchmarks with vertical datums throughout the study area between June and August 2012 (table 3). Differences in elevations between NGS benchmarks and those determined using survey equipment at the benchmarks yielded a vertical root mean square error of 0.15 ft.

[1]Photographs of the HWMs are available by contacting the Chief of the Massachusetts-Rhode Island Office of the New England Water Science Center, dc_ma@usgs.gov.

Table 3. Quality assurance of survey equipment used by the U.S. Geological Survey to determine positions of high-water marks from tropical storm Irene relative to National Geodetic Survey benchmarks in and near the Deerfield and Hudson-Hoosic River Basins, western Massachusetts, June through August 2012.

[NAD 83, North American Datum of 1983; NAVD 88, North American Vertical Datum of 1988; NGS, National Geodetic Survey; ft, feet; WGS 84, World Geodetic System of 1984]

Date	Benchmark		County	Surveyed, in NAD 83[1]			NGS reference, NAVD 88 elevation, adjusted (ft)	Elevation difference between NGS and surveyed values (ft)
	Designation (stamped name)	Permanent identifier		Latitude (north) Decimal degrees	Longitude (west) Decimal degrees	NAVD 88 elevation (ft)		
Trimble TSC2® Survey Unit								
6/5/2012	P9	MZ0415	BERKSHIRE	42.632368	73.113672	759.88	760.02	0.14
6/7/2012	L9	MZ0409	BERKSHIRE	42.553868	73.165154	974.58	974.67	0.09
6/12/2012	E11	MZ0280	FRANKLIN	42.616148	72.743125	506.44	506.36	-0.08
6/14/2012	X40	MZ1181	FRANKLIN	42.580416	72.599227	144.21	144.19	-0.02
6/19/2012	S5	MZ0232	FRANKLIN	42.568834	72.591037	188.66	188.66	0.00
6/21/2012	X40	MZ1181	FRANKLIN	42.580416	72.599227	144.10	144.19	0.09
8/2/2012	X40	MZ1181	FRANKLIN	42.580416	72.599227	144.39	144.19	-0.20
8/10/2012	S5	MZ0232	FRANKLIN	42.568834	72.591037	188.68	188.66	-0.02
8/21/2012	S5	MZ0232	FRANKLIN	42.568834	72.591037	188.59	188.66	0.07
8/23/2012	D33 NEPA	MZ0286	FRANKLIN	42.560074	72.678673	240.19	240.29	0.10
Trimble TSC3® Survey Unit								
6/6/2012	N11	MZ0369	BERKSHIRE	42.738259	73.210933	593.49	593.57	0.08
6/13/2012	X40	MZ1181	FRANKLIN	42.580416	72.599227	144.17	144.19	0.02
6/15/2012	Y9	MZ0287	FRANKLIN	42.561383	72.679986	240.34	240.42	0.08
6/21/2012	D33 NEPA	MZ0286	FRANKLIN	42.560075	72.678673	240.49	240.29	-0.20
6/26/2012	X40	MZ1181	FRANKLIN	42.580416	72.599227	144.14	144.19	0.05
7/12/2012	J33	MZ0266	FRANKLIN	42.642113	72.923880	601.82	602.19	0.37
7/12/2012	F11	MZ0265	FRANKLIN	42.642158	72.924815	603.21	603.30	0.09
7/17/2012	E11	MZ0280	FRANKLIN	42.616147	72.743124	506.62	506.36	-0.26
7/19/2012	E11	MZ0280	FRANKLIN	42.616148	72.743125	506.65	506.36	-0.29
8/15/2012	X40	MZ1181	FRANKLIN	42.580416	72.599227	144.01	144.19	0.18
8/21/2012	S5	MZ0232	FRANKLIN	42.568834	72.591037	188.72	188.66	-0.06

[1]Units of the original horizontal survey were in WGS 84; transformation to NAD 83 results in negligible differences.

Uses of Data

HWM elevations are used in hydrologic studies in several ways: to confirm peak river stages, to help compute peak streamflows, to calibrate hydraulic models, and to update flood inundation and flood insurance rate maps. In western Massachusetts, HWMs from tropical storm Irene have been used to determine or confirm instantaneous peak river gage heights at 10 USGS streamgages, 2 of which were up to 20 miles outside the study area. For example, at USGS streamgage Deerfield River at Charlemont (01168500), flood streamflows overtopped the instrument shelter, and HWMs were used to determine the peak river gage height that would otherwise have been lost. At USGS streamgages North River at Shattuckville (01169000), South River near Conway (01169900), Green River near Colrain (01170100), West Branch Westfield River at Huntington (01181000, outside the study area), and Green River at Williamstown (01333000), the HWMs were used to adjust the streamgages recorded peak gage heights to higher values; this was needed to fix values that were incorrectly recorded too low as a result of drawdown or intakes with slow response times. At USGS streamgages Deerfield River near West Deerfield (01170000), Mill River at Northampton (01171500, outside the study area), Hoosic River at Adams (01331500), and Hoosic River near Williamstown (01332500), HWMs were used to confirm peak river stages that were either recorded electronically or observed from a crest-stage gage.

Summary

On August 28–29, 2011, intense rainfall from tropical storm Irene of 3 to 10 inches caused widespread flooding in western Massachusetts. August precipitation in western Massachusetts prior to tropical storm Irene had already saturated the ground resulting in conditions prone to flooding. Eight of 16 long-term U.S. Geological Survey (USGS) streamgages in western Massachusetts that had been in operation for more than 25 years recorded new streamflow peaks from tropical storm Irene. In order to document the peak river stage elevations from tropical storm Irene in western Massachusetts, the Federal Emergency Management Agency authorized a Mission Assignment for the USGS to identify and flag high-water marks (HWMs) along affected river reaches in the Deerfield and Hudson-Hoosic River Basins and to survey their elevations.

From August 31 through September 30, 2011, the U.S. Geological Survey identified and flagged 323 HWMs: 260 in the Deerfield River Basin at 104 locations on 12 different stream reaches and 63 in the Hudson-Hoosic River Basin at 30 locations on 3 different stream reaches. The HWMs were typically identified upstream and downstream from structures (bridges, dams, and wastewater-treatment facilities, or USGS streamgages) on the selected river reaches. At each flagged HWM, information including the physical description of the HWM, horizontal location (latitude and longitude), rating of accuracy, description of the durable marker left by the USGS crew, and directions for finding the HWM at a later date by survey crews, was recorded on field forms. In addition, photographs of the HWM and surrounding area were taken.

Elevations of HWMs were surveyed from June through August 2012, and April and May 2013 vertically to the North American Vertical Datum of 1988 (NAVD 88) and horizontally to the North American Datum of 1983 (NAD 83) using the Global Navigation Satellite System, survey grade Global Positioning System (GPS) receivers, and total station surveying equipment. Continuous real-time differential corrections to the GPS positions were made using a proprietary fixed-base station GPS network of receivers. Quality-assurance GPS measurements made at 10 established National Geodetic Survey benchmarks with a vertical datum throughout the study area yielded a vertical root mean square error of 0.15 feet. Five of the original 323 HWM elevations that could not be found were surveyed at estimated points.

Acknowledgments

The authors thank the following U.S. Geological Survey (USGS) field personnel for identifying and flagging high-water marks during September 2011: Christopher Bruet, Paul Friesz, Pam Lombard, Steven O’Brien, John O’Byran, Gene Parker, David Thompson, and Andrew Waite. The authors thank the following USGS field personnel for surveying high-water marks from June through August 2012, and April and May 2013: Roy Apostle, David Armstrong, Dennis Claffey, Adam Hudziec, Andrew Massey, and William Podolski. The authors also thank the many landowners who allowed access to their property to identity, flag, and survey high-water marks.

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Appendix 1. Elevations of High-Water Marks Surveyed in the Deerfield and Hudson-Hoosic River Basins in Northwestern Massachusetts Resulting from Flooding from Tropical Storm Irene, August 28–29, 2011

[Available separately at http://pubs.usgs.gov/ds/775/]

Appendix 2. GoogleEarth Map of High-Water Marks in the Deerfield and Hudson-Hoosic River Basins in Northwestern Massachusetts Resulting from Flooding from Tropical Storm Irene, August 28–29, 2011

[Available separately at http://pubs.usgs.gov/ds/775/]

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