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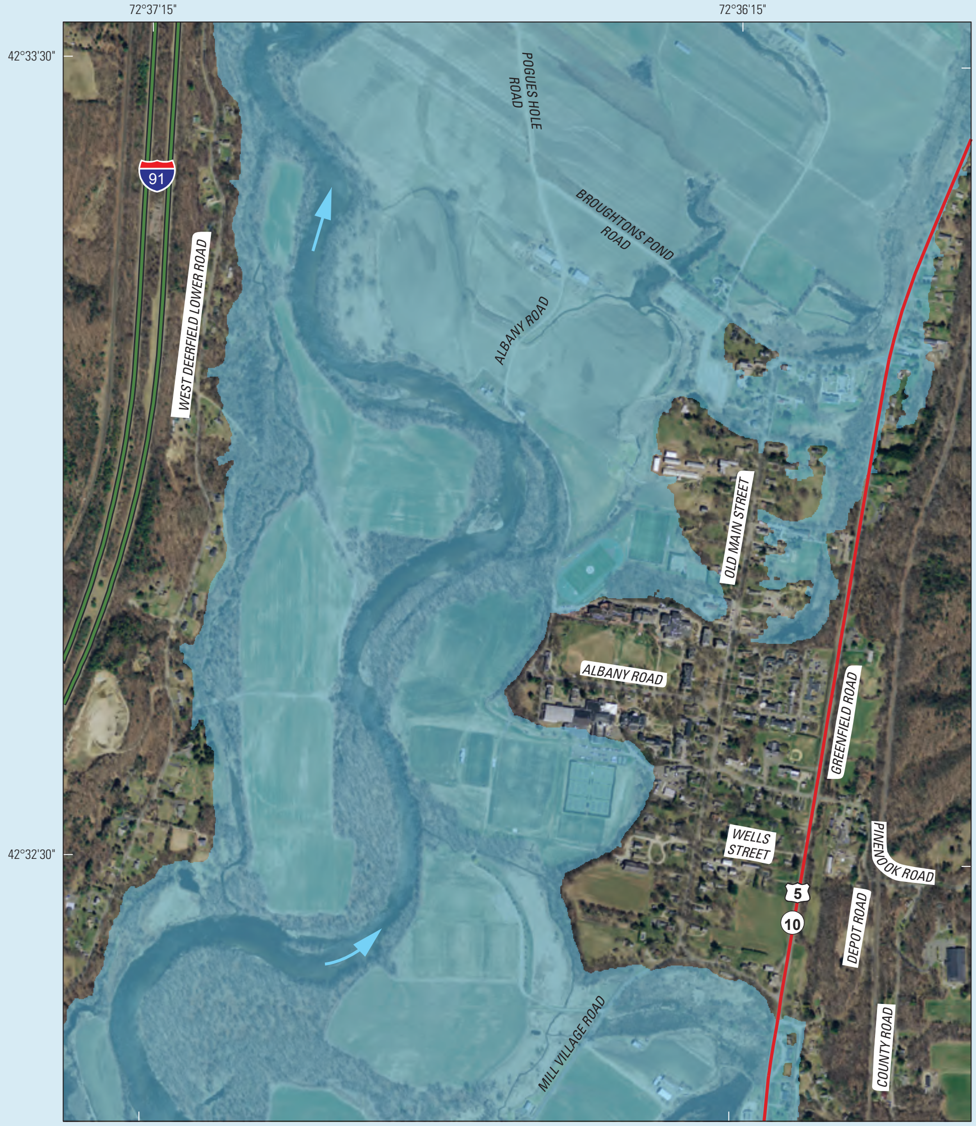
Flood-Inundation Maps for the Deerfield River, Franklin County, Massachusetts, From the Confluence With the Cold River Tributary to the Connecticut River



Scientific Investigations Report 2015–5104

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

Cover. Flood inundation map for a region on the Deerfield River near Deerfield, Massachusetts, corresponding to a stage of 23.8 feet (approximately the 0.5 percent annual exceedance probability flood) and approximately depicts the August 28, 2011 tropical storm Irene peak flow at the U.S. Geological streamgage Deerfield River near West Deerfield, MA (01170000).

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By Pamela J. Lombard and Gardner C. Bent

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U.S. Geological Survey
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Conversion Factors

Inch/Pound to International System of Units

Multiply	By	To obtain
	Length	
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)

Datum

Vertical coordinate information is referenced to either stage (the height above an arbitrary datum established at a streamgage) or elevation (the height above 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 arbitrary local datum or distance above NAVD 88.

Abbreviations

AEP	annual exceedance probability
AHPS	Advanced Hydrologic Prediction Service
DEM	digital elevation model
DGPS	differential global positioning system
FEMA	Federal Emergency Management Agency
GIS	geographic information system
HWM	high-water mark
lidar	light detection and ranging
NWS	National Weather Service
RTK	real-time kinematic
USGS	U.S. Geological Survey
WIE	Weighted Independent Estimator [program]

Flood-Inundation Maps for the Deerfield River, Franklin County, Massachusetts, From the Confluence With the Cold River Tributary to the Connecticut River

By Pamela J. Lombard and Gardner C. Bent

Abstract

The U.S. Geological Survey developed flood elevations in cooperation with the Federal Emergency Management Agency for a 30-mile reach of the Deerfield River from the confluence of the Cold River tributary to the Connecticut River in the towns of Charlemont, Buckland, Shelburne, Conway, Deerfield, and Greenfield in Franklin County, Massachusetts to assist land owners, and emergency management workers prepare for and recover from floods. Peak flows with 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent annual exceedance probabilities were computed for the reach from updated flood-frequency analyses. These peak flows were routed through a one-dimensional step-backwater hydraulic model to obtain the corresponding peak water-surface elevations and to place the tropical storm Irene flood of August 28, 2011 into historical context. The hydraulic model was calibrated by using current [2015] stage-discharge relations at two U.S. Geological Survey streamgages in the study reach—Deerfield River at Charlemont, MA (01168500) and Deerfield River near West Deerfield, MA (01170000)—and from documented high-water marks from the tropical storm Irene flood, which had between a 1- and 0.2-percent AEP.

The hydraulic model was used to compute water-surface profiles for flood stages referenced to the two streamgages. Two sets of flood-inundation map libraries were created from the modeled profiles. The library for the upstream, western portion of the modeled reach is 9.1 miles long, extends from just downstream of the confluence of the Deerfield River with the Cold River to just upstream of the confluence with Clesson Brook, and is calibrated to the Deerfield River at Charlemont, MA streamgage. The library for the downstream, eastern portion of the modeled reach is 8.9 miles long, extends from just downstream of the confluence of the Deerfield River with the South River to just upstream of the confluence with the Green River, and is calibrated to the Deerfield River near West Deerfield streamgage. Stages for mapped profiles of the upstream reach range from 8.7 feet (ft) at the local datum (525.6 ft when converted to the North American Vertical Datum of 1988 [NAVD 88]) to 25.7 ft (542.6 ft at NAVD 88) at the Charlemont streamgage, and stages for mapped profiles of the downstream reach range from 8.5 ft (165.2 ft at NAVD 88) to 29.0 ft (185.7 ft at NAVD 88) at the West Deerfield streamgage. The simulated water-surface profiles were combined with a geographic information system digital elevation model derived from 0.5-ft vertical accuracy light detection and ranging (lidar) data to create the two sets of flood-inundation maps.

The availability of the flood-inundation maps at http://water.usgs.gov/osw/flood_inundation/, combined with information regarding current (near real-time) stage from the two U.S. Geological Survey streamgages in the study reach, can provide emergency management personnel and residents with information to aid in flood response activities, such as evacuations and road closures, and with postflood recovery efforts. The flood-inundation maps are nonregulatory, but provide Federal, State, and local agencies and the public with estimates of the potential extent of flooding during selected peak-flow events.

Introduction

On August 22, 2011, Hurricane Irene travelled up the east coast of the United States affecting States from South Carolina to Maine. The large, category 1 hurricane buffeted the area with heavy rains, damaging winds, and storm surge, which resulted in damages estimated in the billions of dollars (Federal Emergency Management Agency, 2013). Although the hurricane was downgraded to a tropical storm before entering New England on August 28, 2011, it brought a period of intense rainfall with totals ranging from 3 to 10 inches over western Massachusetts. The rainfall and resulting runoff caused several rivers in western Massachusetts to peak at record levels during August 28–29, 2011. In many cases, the stage-discharge rating curves were exceeded at U.S. Geological Survey (USGS) streamgages that had been in operation for decades. Tropical storm Irene resulted in peak flows on August 28, 2011, at USGS streamgages in the Deerfield River Basin that ranged from 1- to less than 0.2-percent annual exceedance probability (AEP) floods (fig. 1; table 1).

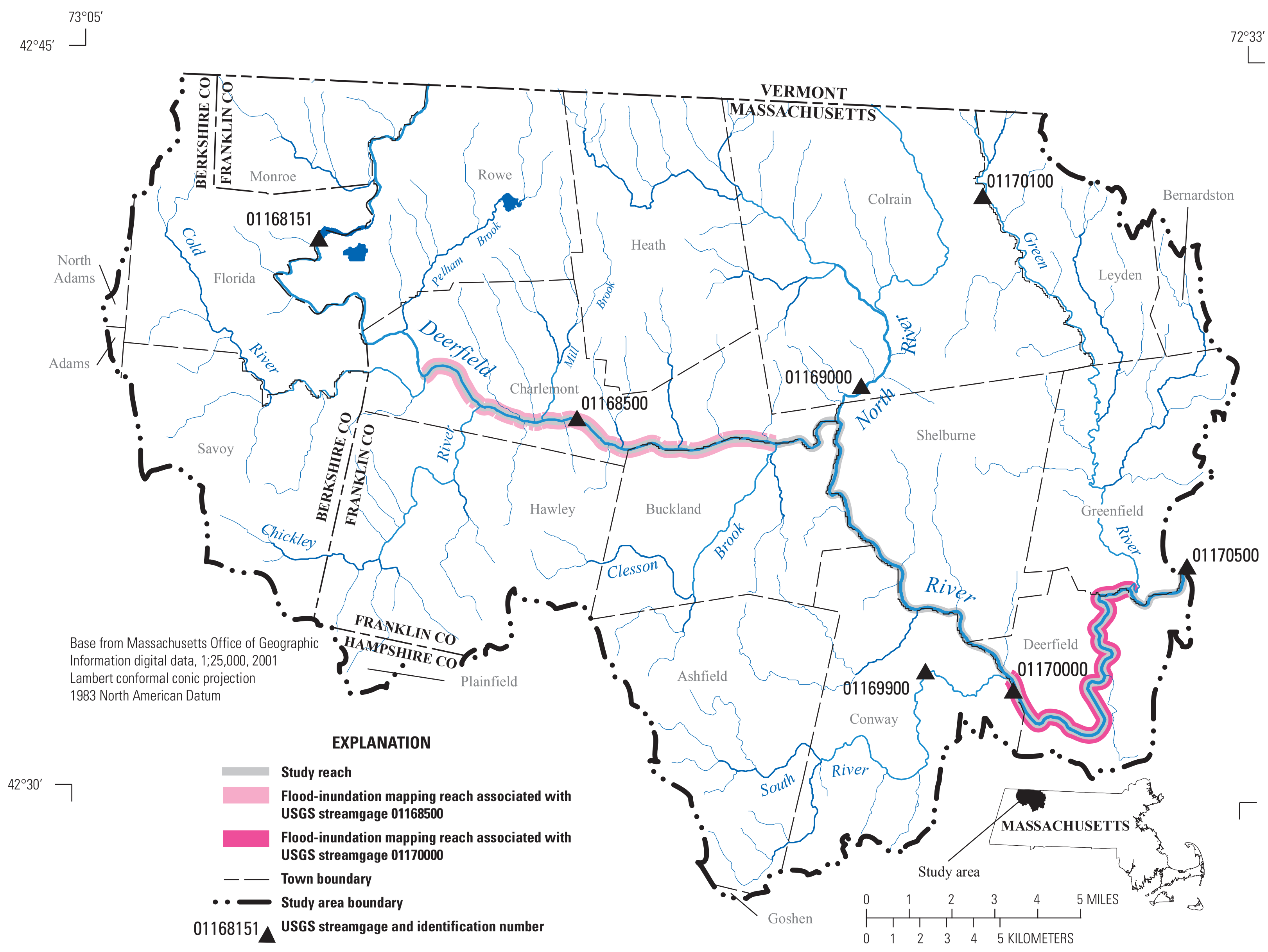

Figure 1. Location of Deerfield River study reach and flood-inundation mapping (FIM) library reaches in Franklin County, Massachusetts, and U.S. Geological Survey (USGS) streamgages in the region.

Table 1. Peak discharges and annual exceedance probabilities at U.S. Geological Survey streamgages at and around the Deerfield River in Franklin County, Massachusetts, during tropical storm Irene on August 28, 2011.

[Streamgage locations are shown in figure 1. ft^3/s, cubic feet per second; <, less than]

Station name	Station number	Flow, in ft^3/s	Annual exceedance probability, in percent
Deerfield River at Charlemont, MA	01168500	54,000[a]	1
Deerfield River near West Deerfield, MA	01170000	89,800[b]	0.5
North River at Shattuckville, MA	01169000	30,300[b]	0.2
South River near Conway, MA	01169900	9,300[b]	1 to 0.5
Green River near Colrain, MA	01170100	13,200[b]	<0.2
Connecticut River at Montague City, MA	01170500	127,000[a]	10

[a] Flow and annual exceedance probabilities published in Olson and Bent (2013).

[b] Flow determined from an indirect flow measurement using either slope-area computations (Dalrymple and Benson, 1967) or the contracted-width opening techniques (Matthai, 1967).

On September 3, 2011, a presidential disaster declaration (FEMA–4028–DR) was issued for Berkshire and Franklin Counties in western Massachusetts (Federal Emergency Management Agency, 2013). On October 20, 2011, two other counties in western Massachusetts and five other counties in southeastern Massachusetts were added to this declaration. As of February 2013, Federal financial assistance to Massachusetts for recovery from tropical storm Irene exceeded $11 million for individual assistance and $53 million for public assistance (Federal Emergency Management Agency, 2013).

Damages in the Deerfield River Basin were located throughout the basin, including along the main stem of the Deerfield River and along many of the tributaries to the Deerfield River. Numerous homes, businesses, schools, municipal infrastructure, and agricultural fields along the Deerfield River were flooded, specifically in Buckland, Charlemont, Deerfield, Greenfield, and Shelburne (Massachusetts Emergency Management Agency, 2011). During the height of tropical storm Irene and in some cases for several days following the storm, several bridges over the Deerfield River and roads in western Massachusetts were closed, such as the bridges over the Deerfield River on Route 8A, Route 2A, Stillwater Road, and U.S. Interstate I–91 (Abel, 2011; Johnson, 2011; Kinney, 2011a; Republican Newsroom, The, 2011; Schworm and Lutz, 2011). One building, a quilt store in Buckland, was washed away from its foundation and deposited downstream a few hundred feet (Barry, 2011). The Greenfield wastewater treatment plant on the Green River near its confluence with the Deerfield River was inundated by flood waters, resulting in a shutdown and untreated wastewater discharging to the Deerfield and Connecticut Rivers (Graham, 2011). Tropical storm Irene resulted in more than $90 million in insurance claims in western Massachusetts, including more than $750,000 in Franklin County (Kinney, 2011b). Damages in the town of Deerfield were reported to the village of Old Deerfield, Deerfield Academy, the Bement School, municipal infrastructure, and farm fields (Gilmore and others, 2011). The town of Greenfield estimated damages of $11 million, mainly to the town's infrastructure (Stabile, 2011). The Federal Government provided $40.7 million to finance repairs to roads and bridges in western Massachusetts as a result of tropical storm Irene (Flynn, 2012).

In response to the presidential disaster declaration for Massachusetts, a Federal Emergency Management Agency (FEMA) mission assignment was authorized for the USGS to locate and survey the elevations of high-water marks (HWMs) in the Deerfield River Basin from the confluence of the Cold River tributary to the Connecticut River in Franklin County, Massachusetts. An April 2012 interagency agreement between FEMA (Region I, New England) and the USGS authorized the development of two sets of flood-inundation maps that would cover a range of stages from bankfull to the highest recorded stages at each of the two streamgages. River stage data from these streamgages are referenced to a local datum, but can be converted to water-surface elevations referenced to the North American Vertical Datum of 1988 (NAVD 88) by adding 516.93 ft at the Charlemont streamgage and 156.74 ft at the West Deerfield streamgage. Flood stages are mapped from 8.7 feet (ft; 525.6 ft at NAVD 88) to 25.7 ft (542.6 ft at NAVD 88) at the Charlemont streamgage; and from 8.5 ft (165.2 ft at NAVD 88) to 29.0 ft (185.7 ft at NAVD 88) at the West Deerfield streamgage. Initial stages were selected for mapping that corresponded to flows with AEPs between 50- and 0.2 percent to meet FEMA's flood recovery map criteria. If AEP stages were greater than 2 ft apart from each other at the streamgage, then additional profiles were added to make a smooth transition between flood-inundation maps. The flood of August 28, 2011, corresponds to a flood with an AEP between about the 1- and 0.5-percent on the studied reach of the Deerfield River.

Before this study, emergency responders in the communities of Buckland, Charlemont, Conway, Deerfield, Greenfield, and Shelburne relied on several information sources to make decisions on how to best alert the public and mitigate flood damages. One such source includes the FEMA flood insurance studies for each of these municipalities (Federal Emergency Management Agency, 1979a,b, 1980a–d). A second source of information are the data from the Charlemont and Deerfield streamgages from which current [2015] and historical (since 1913 and 1940, respectively) river stages and discharges, including annual peak flows, can be obtained (table 2; U.S. Geological Survey, 2014a,b).

Although knowing the real-time river stage at a USGS streamgage is useful for residents in the immediate vicinity of a streamgage, it is of limited use to residents upstream or downstream from the streamgage because the water-surface elevation is not constant along the entire stream reach. Knowledge of a water level at a streamgage is difficult to translate into depth and areal extent of flooding at points distant from the streamgage. One way to address these informational gaps is to produce flood-inundation map libraries that are referenced to the flood stages recorded at USGS streamgages. By referring to the appropriate map, emergency responders can discern the severity of flooding (depth of water and areal extent), identify roads that are or are likely to be flooded soon, and make plans for notification or evacuation of residents in danger for some distance upstream and downstream from the streamgage. In addition, the capability to visualize the potential extent of flooding has been shown to motivate residents to take precautions and heed warnings that they previously might have disregarded.

Purpose and Scope

This report describes the development of a hydraulic model for a 30-mile (mi) reach of the Deerfield River in Franklin County, from the confluence with the Cold River tributary to the Connecticut River. This report also describes the flow frequency analyses that were used as hydrologic input to the hydraulic model and the creation of two sets of flood-inundation maps for the modeled section of the river. The upstream set of flood-inundation maps covers a distance 9.1 mi long, extending from just downstream of the confluence with the Cold River to just upstream of the confluence with Clesson Brook, and is calibrated to the Charlemont streamgage. The downstream set covers a distance 8.9 mi long, extending from just downstream of the confluence with the South River to just upstream of the confluence with the Green River, and is calibrated to the West Deerfield streamgage. The maps cover ranges in stage that correspond with the 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent AEP flows that were computed based on the peak-flow records of the two streamgages. The two sets of flood-inundation maps were developed for display on the USGS Flood Inundation Mapper Web site (http://wimcloud.usgs.gov/apps/FIM/FloodInundationMapper.html).

Study Area Description

The study reach of the Deerfield River is in Franklin County in the northwestern part of Massachusetts. The entire reach studied for the computation of statistical flows associated with AEPs flows east from where the Cold River tributary joins the Deerfield River in Charlemont, Mass., about 800 ft upstream of the Railroad Bridge at the Tea Street Extension. The river flows through Buckland, Shelburne, Conway, Deerfield, and Greenfield (fig. 1) and has a drainage area of 664 square miles (mi^2) at the mouth. Two shorter reaches within this longer reach were used to create flood-inundation map libraries—one associated with each streamgage within the longer reach. There are several tributaries to the Deerfield River within the study reach: Chickley River (27.5-mi^2 drainage area), Mill Brook (11.9-mi^2 drainage area), Clesson Brook (21.3-mi^2 drainage area), North River (93-mi^2 drainage area), South River (26.3-mi^2 drainage area), and Green River (89-mi^2 drainage area). The Charlemont streamgage is approximately 0.9 mi downstream of the town of Charlemont and the Mill

Table 2. Information about U.S. Geological Survey streamgages Deerfield River at Charlemont, MA (01168500) and Deerfield River near West Deerfield, MA (01170000).

[Streamgage locations are shown in figure 1. NAD 83, North American Datum of 1983; NAVD 88, North American Vertical Datum of 1988; mi^2, square mile; ft, foot; ft^3/s, cubic foot per second]

Station name	Deerfield River at Charlemont, MA	Deerfield River near West Deerfield, MA
Station number	01168500	01170000
Drainage area	361 mi^2	557 mi^2
Latitude (decimal degrees, NAD 83)	42.626000	42.535920
Longitude (decimal degrees, NAD 83)	72.854194	72.653423
Period of peak-flow record, in water years[a]	1913–present	1941–present
Maximum recorded stage, streamgage datum (elevation above NAVD 88), and dates	20.17 ft; 537.10 ft; September 21, 1938, and August 28, 2011	23.77 ft; 180.51 ft; August 28, 2011
Maximum discharge and date[b]	56,300 ft^3/s, September 21, 1938	89,800 ft^3/s, August 28, 2011

[a]A water year is the 12-month period from October 1 of one year through September 30 of the following year and is designated by the calendar year in which it ends.

[b]The maximum discharge is affected to an unknown degree by regulation of flow due to upstream hydroelectric dams.

Brook tributary (fig. 1) and collects data for a drainage area of 361 mi^2. The West Deerfield streamgage is approximately 0.4 mi downstream of the South River tributary and approximately 9.5 mi upstream of the mouth and collects data for a drainage area of 557 mi^2. The study reach is traversed by 14 bridges and includes 4 dams. The four dams (dam numbers 4, 3, Gardner Falls, and 2 in downstream order) on the study reach have been operated on the Deerfield River since the early 1900s (Low Impact Hydropower Institute, 2011 and 2012; TransCanada, 2012).

Creation of Flood-Inundation Map Libraries

The USGS has standardized procedures for creating flood-inundation maps for flood-prone communities. Tasks specific to development of the flood maps for this study of the Deerfield River were (1) collection of topographic and bathymetric data for selected cross sections of geometric data for structures and bridges along the study reach, (2) estimation of energy-loss factors (roughness coefficients) in the stream channel and flood plain and determination of steady-flow data, (3) computation of water-surface profiles using the U.S. Army Corps of Engineers HEC–RAS computer program (U.S. Army Corps of Engineers, Hydrologic Engineering Center, 2010), (4) production of estimated flood-inundation maps at various flood stages using the U.S. Army Corps of Engineers HEC–GeoRAS computer program (U.S. Army Corps of Engineers, Hydrologic Engineering Center, 2009) and a geographic information system (GIS), and (5) preparation of the flood-inundation maps, both as shapefile polygons that depict the areal extent of flood inundation and as depth grids that provide the depth of floodwaters, for display on an online USGS flood-inundation mapping application.

Computation of Water-Surface Profiles

The water-surface profiles used to produce 15 flood-inundation maps calibrated to the Charlemont streamgage and 17 flood-inundation maps calibrated to the West Deerfield streamgage were computed using HEC–RAS (version 4.1.0; U.S. Army Corps of Engineers, Hydrologic Engineering Center, 2010). HEC–RAS is a one-dimensional step-backwater model for simulation of water-surface profiles. The model was used with the steady-state (gradually varied) option.

Hydrology

The upstream study reach of the Deerfield River from downstream of the Cold River tributary to upstream of the confluence with Clesson Brook is 9.1 mi long, has a drainage area of 405 mi^2 just upstream of the North River tributary, and includes the Charlemont streamgage, which has been in operation since 1913 (table 2). The Charlemont streamgage is 0.9 mi downstream of the town of Charlemont and the Mill Brook tributary (fig. 1). The downstream reach runs from just downstream of the confluence with the South River to just upstream of the confluence with the Green River, has a drainage area of 663 mi^2 at the mouth, and includes the West Deerfield streamgage, which has been in operation since 1940 (table 2). The West Deerfield streamgage is 0.4 mi downstream of the South River tributary and 9.5 mi upstream of the mouth (fig. 1). River stage for both streamgages is measured every 15 minutes, transmitted hourly via satellite, and is available from the USGS (U.S. Geological Survey, 2014a,b). Continuous records of streamflow at the streamgages are computed from stage-discharge relations (rating curves) developed through concurrent stage and streamflow measurements that are available from the USGS (U.S. Geological Survey, 2014a,b).

Flows for the 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent AEP floods at the Charlemont and West Deerfield streamgages were determined by the standard log-Pearson type III method described in U.S. Interagency Advisory Committee on Water Data (1982) and a modification of this method called the expected moments algorithm (EMA; table 3; Cohn and others, 1997, 2001; Griffis and others, 2004). These at-site analyses are based on 100 years of record at the Charlemont streamgage (water years 1914–2013) and 73 years of record (water years 1941–2013) at the West Deerfield streamgage. Uncertainties associated with the peak flow analyses used to estimate flood flows with given annual exceedance probabilities are also shown in table 3. No weighted or regional AEP flood flow estimates were calculated because the streamflow upstream of the streamgages is affected by hydroelectric dams; thus, the gaged flows are the most appropriate flows to use in this case.

Flows with the given AEPs were transferred about 4.3 mi upstream and 9.5 mi downstream from the two Deerfield River streamgages (fig. 1) using a drainage-area ratio method (Johnstone and Cross, 1949). Locations and estimates of streamflow for the given AEPs are presented in table 4. The drainage-area-ratio equation from Johnstone and Cross (1949) is as follows:

$$Q_{P(u)DAR} = \left(\frac{DA_u}{DA_g} \right)^b Q_{P(g)} , \qquad (1)$$

where

$Q_{P(u)DAR}$ is the drainage-area-ratio weighted estimate of discharge Q_P

$Q_{P(g)}$ is the discharge for the selected AEP percent (P) at the gaged site (g) derived from the station records,

DA_u is the drainage area at the ungaged site,

DA_g is the drainage area at the gaged site, and

b is the exponent of the drainage-area only regional regression equations for the appropriate AEP (table 5).

Table 3. Flood flows of given annual exceedance probabilities and the uncertainties associated with the estimates for U.S. Geological Survey streamgages Deerfield River at Charlemont, MA (01168500) and Deerfield River near West Deerfield, MA (01170000).

[Streamgages are shown in figure 1 and described in table 2. %, percent; ft³/s, cubic foot per second]

Annual exceedance probability, in %	Peak flow, in ft³/s	Variance of estimate	95% confidence interval, in ft³/s	95% upper confidence interval, in ft³/s
Station 01168500, Deerfield River at Charlemont, MA				
50	11,000	0.0008	9,670	12,500
20	18,600	0.0011	16,200	22,100
10	25,100	0.0017	21,300	31,700
4	35,200	0.0033	28,500	50,700
2	44,100	0.0051	34,400	72,200
1	54,500	0.0075	40,700	102,400
0.5	66,500	0.0105	47,500	145,000
0.2	85,300	0.0154	57,200	228,700
Station 01170000, Deerfield River near West Deerfield, MA				
50	16,100	0.0008	14,100	18,400
20	25,400	0.0013	21,800	30,900
10	33,500	0.0022	28,100	44,800
4	46,500	0.0046	36,900	77,500
2	58,600	0.0076	44,200	123,000
1	73,000	0.0117	52,200	200,200
0.5	90,200	0.0170	61,000	302,500
0.2	118,100	0.0259	73,900	522,700

Table 4. Estimated discharges for the 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent annual exceedance probability floods and the tropical storm Irene flood (August 28, 2011) at selected locations on the Deerfield River in Franklin County, Massachusetts.

[Streamgages are shown in figure 1 and described in table 2. USGS, U.S. Geological Survey; mi², square mile; ft³/s, cubic foot per second; %, percent]

Location on Deerfield River	Drainage area, in mi²	Estimated discharge, in ft³/s, for annual exceedance probabilities								Peak flow August 28, 2011 (tropical storm Irene), in ft³/s
		50%	20%	10%	4%	2%	1%	0.5%	0.2%	
Confluence with Connecticut River	663	18,700	28,800	37,600	51,900	65,700	81,900	101,800	134,500	109,900
About 800 feet upstream of bridge on U.S. Route 5 and State Route 10 at town border of Deerfield and Greenfield	571	16,400	25,800	34,000	47,200	59,500	74,100	91,600	120,100	92,200
USGS streamgage 01170000	557	16,100	25,400	33,500	46,500	58,600	73,000	90,200	118,100	89,800
Upstream of South River confluence	532	15,400	24,500	32,400	45,100	56,800	70,700	87,200	113,900	84,800
Upstream of North River confluence	405	12,100	20,100	27,000	37,800	47,400	58,800	72,000	92,800	61,600
USGS streamgage 01168500	361	11,000	18,600	25,100	35,200	44,100	54,500	66,500	85,300	54,000
West Hawley Road (State Route 8A) bridge, Charlemont	339	10,400	17,800	24,000	33,800	42,200	52,300	63,700	81,300	50,200

Table 5. Exponent of drainage area used to calculate flood flows for the given annual exceedance probabilities for the Deerfield River in Franklin County, Massachusetts.

Annual exceedance probability, in percent	Exponent of drainage area[1]
50	0.88
20	0.72
10	0.67
4	0.64
2	0.66
1	0.67
0.5	0.70
0.2	0.75
Flood peak flow on August 28, 2011 (tropical storm Irene)	1.17

[1]Exponent of drainage area is variable *b* used in equation 1 of this report.

Upstream and downstream values were calculated by using the published drainage areas at the streamgages (table 2) and the AEP flows as published for each streamgage. The formula used is the following:

$$b = \frac{\log 10 \frac{AEP\ Q_{West\ Deerfield}}{AEP\ Q_{Charlemont}}}{\log 10 \frac{DA_{West\ Deerfield}}{DA_{Charlemont}}}, \tag{2}$$

where

$Q_{West\ Deerfield}$ is the discharge at the Deerfield River near West Deerfield, MA (01170000) streamgage;

$Q_{Charlemont}$ is the discharge at the Deerfield River at Charlemont, MA (01168500) streamgage;

$DA_{West\ Deerfield}$ is the drainage area at the Deerfield River near West Deerfield, MA (01170000) streamgage; and

$Q_{Charlemont}$ is the drainage area at the Deerfield River at Charlemont, MA (01168500) streamgage.

Topographic and Bathymetric Data

All topographic data used in the model are referenced vertically to the NAVD 88 and horizontally to the North American Datum of 1983 (NAD 83). Cross-section elevation data were obtained from a digital elevation model (DEM) that was derived from light detection and ranging (lidar) data that were collected during March and April 2012 by Northrop Grumman Information Systems, Advanced GEOINT Solutions Operating Unit. The original lidar data have a vertical accuracy of 0.5 ft at a 95-percent confidence level for the bare-earth terrain land-cover category. By these criteria, the lidar data support production of 2-ft contours (Snyder and others, 2014). The final DEM was resampled to a 6.5-ft grid-cell size to decrease the GIS processing time. By using HEC–GeoRAS, a set of procedures, tools, and utilities for processing geospatial data in Esri ArcGIS, elevation data were extracted from the DEM for 151 cross sections and subsequently input to the HEC–RAS model. Because lidar data cannot provide ground elevations below the water surface of a stream, channel cross sections were surveyed by USGS field crews. A differential global positioning system (DGPS) with real-time kinematic (RTK) technology was used to derive horizontal locations and the elevation of the water surface at each surveyed cross section during August through December 2013 and hydraulic structure (bridges and dams) during September through December 2012. Twenty-nine measurements of the elevations at four National Geodetic Survey benchmark (permanent identification numbers MZ0232, MZ0280, MZ0286, and MZ1181) locations in Franklin County differed from their known elevations by 0.001 to 0.384 ft. The median difference of these 29 RTK DGPS measurements from the known elevations of these four benchmarks was 0.084 ft.

Where possible, DEM-generated cross sections were made to coincide with the locations of the within-channel field-surveyed cross sections. In these cases, within-channel data were directly merged with the DEM data. For all other cross sections, the within-channel data were estimated by interpolation from the closest field-surveyed cross section.

Hydraulic Model

The hydraulic model for this study was developed using HEC–RAS (version 4.1.0; U.S. Army Corps of Engineers, Hydrologic Engineering Center, 2010). Eighteen structures (table 6), consisting of 14 bridges and 4 dams, have the potential to affect water-surface elevations during floods along the stream reach. Hydraulic analyses require the estimation of energy losses that result from frictional resistance exerted by a channel on flow. These energy losses are quantified by the Manning's roughness coefficient (*n*-value). Initial (precalibration) *n*-values were selected on the basis of field observations and high-resolution aerial photographs. The section of the study area in the highest elevations (upstream section) is primarily wooded with dense vegetation as is the riparian corridor throughout the entire reach. The middle section of the reach is steeper than the upper section and is characterized by residential development. The lower end of the reach is relatively flat and is characterized by farm fields. Calibrated channel *n*-values range from 0.03 to 0.057. Overbank *n*-values vary from 0.05 to 0.09; much of the overbank can be characterized by dense overhanging hardwood vegetation. Slope *n*-values vary from 0.001 to 0.002 in the upper and lower sections of the reach and closer to 0.006 in the middle third of the reach. Bankfull top widths typically are between 300 and 600 ft. As part of the calibration process, the initial *n*-values were adjusted until the differences between simulated and observed water-surface elevations at the streamgage were minimized. Observed water-surface elevations include HWMs and streamgages.

The HEC–RAS analysis was done by using the steady-state flow computation option. Subcritical (tranquil) flow regime was assumed for the simulations. Normal depth was based on an estimated average bed slope of 0.004 ft/ft. The HEC–RAS model was calibrated to the current stage-discharge relation at the Charlemont streamgage (Rating curve number 36.0 from October 22, 2014 to the present [2015]) and the current stage-discharge relation at the West Deerfield streamgage (Rating curve number 15 from November 7, 2014 to the present [2015]) and to documented HWMs from tropical storm Irene in August 2011 (Bent and others, 2013).

Differences between surveyed and modeled elevations of HWMs in the study reach for the August 2011 flood were less than 1 ft for 23 of the 48 HWMs, between 1 and 2.5 feet for 22 of the HWMs, and more than 2.5 ft for 3 of the HWMs (table 7). It is possible for field crews to collect an HWM that is lower than the final water-surface elevation of a flood because marks can be made on the falling limb of the hydrograph. All the HWMs that are more than 2.5 feet different from the modeled water surface elevation are lower than the modeled water surface elevation. In addition, high flows can be extremely turbulent, causing additional error and uncertainty in the HMWs (fig. 2).

Development of Water-Surface Profiles

The calibrated hydraulic model was used to generate 15 water-surface profiles for flood stages from 8.7 ft (525.6 ft at NAVD 88) to 25.7 ft (542.6 ft at NAVD 88) as referenced to the local datum of the Charlemont streamgage (table 8) and 17 water-surface profiles for flood stages from 8.5 ft (165.2 ft at NAVD 88) to 29.0 ft (185.7 ft at NAVD 88) as referenced to the local datum of the West Deerfield streamgage (table 9). Stages were selected to match flood stages with AEPs between 50 and 0.2 percent (floods with recurrence intervals from 2 to 500 years) and thus do not fall at exact 1-ft increments (tables 8 and 9). If AEP stages were greater than 2 ft apart from each other at the streamgage, then additional profiles were added to make a smooth transition between flood-inundation maps. The highest mapped stage of 25.7 ft (stage of the 0.2-percent AEP flood flow) at the Charlemont streamgage exceeds the highest recorded stage of 20.17 ft from the August 28, 2011, flood. The highest mapped stage of 29.0 ft (stage of the 0.2-percent AEP flood flow) at the West Deerfield streamgage exceeds the highest recorded stage of 23.77 ft from the August 28, 2011, flood. Discharges were transferred upstream and downstream from the streamgage using the drainage area methods discussed in the “Hydrology” section. The model-simulated water-surface elevations for 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent AEP floods and 1-percent AEP floodway are tabulated in appendix 1.

Table 6. Bridge crossings and dams on the Deerfield River in Franklin County, Massachusetts.

[ft, foot; Rt., route; #, number; U.S., United States]

River station, in ft[1]	Structure	Name	Municipality
158,337	Bridge	Railroad	Charlemont
153,182	Bridge	State Rt. 2 (Mohawk Trail)	Charlemont
144,178	Bridge	State Rt. 8A (West Hawley Road)	Charlemont
104,883	Bridge	State Rt. 2 (Mohawk Trail)	Charlemont and Buckland
104,143	Dam	Dam number 4 (TransCanada)	Charlemont and Buckland
93,811	Bridge	State Rt. 2 and 112 (Mohawk Trail)	Shelburne and Buckland
90,245	Bridge	Bridge of Flowers	Shelburne and Buckland
90,096	Bridge	Bridge Street	Shelburne and Buckland
89,305	Dam	Dam number 3 (TransCanada)	Shelburne and Buckland
83,885	Dam	Gardner Falls Dam (Essential Power, formerly known as North American Energy Alliance, LLC)	Shelburne and Buckland
73,699	Dam	Dam number 2 (TransCanada)	Shelburne and Conway
62,804	Bridge	Railroad	Shelburne and Conway
60,745	Bridge	Bardwells Ferry Road	Shelburne and Conway
42,331	Bridge	Upper Road (Stillwater Bridge)	Deerfield
39,941	Bridge	U.S. Interstate I–91	Deerfield
5,866	Bridge	U.S. Rt. 5 and State Rt. 10 (Deerfield Street and Greenfield Road)	Greenfield and Deerfield
5,635	Bridge	Railroad	Greenfield and Deerfield
1,954	Bridge	Railroad	Greenfield and Deerfield

[1]River stations reference the distance upstream from the most downstream point in the hydraulic model.

Table 7. Calibration of hydraulic model to water-surface elevations at selected locations along the Deerfield River in Franklin County, Massachusetts, for the tropical storm Irene flood (August 28, 2011).

[Negative values in difference in elevation column indicate that the surveyed elevation was lower than the modeled elevation; ft, foot; ID, identification number; NAVD 88, North American Vertical Datum of 1988]

River station, in ft[1]	High-water mark ID[2]	High-water mark rating[2]	Surveyed water-surface elevation, in ft above NAVD 88		Difference in elevation, in ft
			Surveyed[2]	Modeled	
1,926	HWM-MA-DEERFIELD-002	Good	135.83	133.95	1.88
2,240	HWM-MA-DEERFIELD-001	Good	137.51	135.32	2.19
5,111	HWM-MA-DEERFIELD-009	Fair	138.04	138.57	-0.53
5,540	HWM-MA-DEERFIELD-008	Good	140.06	138.65	1.41
5,605	HWM-MA-DEERFIELD-007	Good	140.24	141.58	-1.34
5,737	HWM-MA-DEERFIELD-005	Fair	139.35	141.57	-2.22
6,494	HWM-MA-DEERFIELD-003	Good	140.82	142.49	-1.20
6,494	HWM-MA-DEERFIELD-004	Excellent	141.29	142.93	-2.11
10,386	HWM-MA-GREEN-065	Good	141.54	143.68	-2.14
10,386	HWM-MA-GREEN-064	Excellent	141.71	143.68	-1.97
10,386	HWM-MA-GREEN-063	Excellent	141.75	143.68	-1.93
24,850	HWM-MA-DEERFIELD-010	Excellent	143.59	144.79	-1.20
27,362	HWM-MA-DEERFIELD-011	Excellent	144.55	145.38	-0.83
34,473	HWM-MA-DEERFIELD-014	Unknown	145.32	147.94	-2.62
39,799	HWM-MA-DEERFIELD-013	Fair	155.45	158.16	-2.71
40,706	HWM-MA-DEERFIELD-012	Excellent	160.07	158.86	1.21
41,800	HWM-MA-DEERFIELD-017	Good	162.01	162.34	-0.33
42,686	HWM-MA-DEERFIELD-016	Good	166.79	172.66	-5.87
50,342	HWM-MA-DEERFIELD-021	Good	180.25	180.30	-0.05
50,486	HWM-MA-DEERFIELD-020	Fair	180.41	180.40	0.04
50,759	HWM-MA-DEERFIELD-018	Good	181.20	181.11	0.09
50,998	HWM-MA-DEERFIELD-019	Good	180.73	181.27	-0.54
73,319	HWM-MA-DEERFIELD-024	Fair	254.81	254.31	0.50
73,729	HWM-MA-DEERFIELD-023	Good	302.06	301.86	0.20
74,315	HWM-MA-DEERFIELD-022	Good	301.84	302.25	-0.41
83,539	HWM-MA-DEERFIELD-027	Good	318.10	317.70	0.40
84,179	HWM-MA-DEERFIELD-025	Good	346.64	347.46	-0.82
87,245	HWM-MA-DEERFIELD-026	Fair	348.79	348.13	0.66
88,700	HWM-MA-DEERFIELD-033	Excellent	360.22	360.51	-0.29
89,796	HWM-MA-DEERFIELD-032	Good	411.75	411.43	0.32
90,068	HWM-MA-DEERFIELD-030	Excellent	409.83	411.22	-1.39
91,329	HWM-MA-DEERFIELD-029	Excellent	418.13	420.30	-2.17
94,300	HWM-MA-DEERFIELD-034	Good	422.65	423.66	-1.01
103,761	HWM-MA-DEERFIELD-039	Good	446.35	446.35	0.00
104,233	HWM-MA-DEERFIELD-038	Excellent	480.53	478.97	1.56
104,848	HWM-MA-DEERFIELD-037	Good	478.66	479.40	-0.74
105,235	HWM-MA-DEERFIELD-036	Good	480.05	479.58	0.47
122,961	HWM-MA-DEERFIELD-040	Good	505.84	507.62	-1.78
136,257	HWM-MA-DEERFIELD-042	Excellent	537.11	537.27	-0.16
141,216	HWM-MA-MILL-207	Excellent	548.01	546.66	1.35

Table 7. Calibration of hydraulic model to water-surface elevations at selected locations along the Deerfield River in Franklin County, Massachusetts, for the tropical storm Irene flood (August 28, 2011).—Continued

[Negative values in difference in elevation column indicate that the surveyed elevation was lower than the modeled elevation; ft, feet; ID, identification number; NAVD 88, North American Vertical Datum of 1988]

River station, in ft[1]	High-water mark ID[2]	High-water mark rating[2]	Surveyed water-surface elevation, in ft above NAVD 88		Difference in elevation, in ft
			Surveyed[2]	Modeled	
144,149	HWM-MA-DEERFIELD-046	Good	552.94	553.00	-0.06
144,321	HWM-MA-DEERFIELD-044	Excellent	554.32	554.40	-0.08
146,736	HWM-MA-DEERFIELD-045	Good	552.15	554.46	-2.31
149,703	HWM-MA-CHICKLEY-223	Good	565.73	564.70	1.03
152,752	HWM-MA-DEERFIELD-048	Fair	571.23	572.49	-1.26
153,480	HWM-MA-DEERFIELD-047	Good	575.27	575.49	-0.22
158,293	HWM-MA-DEERFIELD-050	Fair	592.07	594.19	-2.12
158,526	HWM-MA-DEERFIELD-049	Fair	597.18	597.42	-0.24

[1]River stations reference the distance upstream from the most downstream point in the hydraulic model.

[2]From Bent and others (2013).

Figure 2. Turbulent flows on the Deerfield River at TransCanada number 3 dam at Shelburne Falls, Massachusetts, taken on August 28, 2011, during flood flows from tropical storm Irene. Photograph by ©John Elder Robison used with permission (http://www.johnrobison.com).

Table 8. Stage, elevation, discharge, and annual exceedance probabilities at the Deerfield River at Charlemont, MA streamgage (01168500) for inundated areas mapped on the Deerfield River in Franklin County, Massachusetts.

[Streamgage is shown in figure 1 and described in table 2. ft, foot; NAVD 88, North American Vertical Datum of 1988; ft^3/s, cubic foot per second; NA, not applicable]

Grid identification[a]	Stage at 01168500, in ft	Elevation at 01168500, in ft above NAVD 88	Discharge at 01168500, in ft^3/s	Annual exceedance probability, in percent
CharlemontMA_01	8.7	525.6	11,000	50
CharlemontMA_02	10.0	526.9	14,600	NA
CharlemontMA_03	11.4	528.3	18,600	20
CharlemontMA_04	12.4	529.3	21,800	NA
CharlemontMA_05	13.4	530.3	25,100	10
CharlemontMA_06	14.7	531.6	30,000	NA
CharlemontMA_07	16.0	532.9	35,200	4
CharlemontMA_08	17.0	533.9	39,300	NA
CharlemontMA_09	18.1	535.0	44,100	2
CharlemontMA_10	19.2	536.1	49,200	NA
CharlemontMA_11[b]	20.3	537.2	54,500	1
CharlemontMA_12	21.4	538.3	60,500	NA
CharlemontMA_13	22.5	539.4	66,500	0.5
CharlemontMA_14	24.1	541.0	75,500	NA
CharlemontMA_15	25.7	542.6	85,300	0.2

[a] Grids refer to flood inundation maps on the U.S. Geological Survey flood inundation mapping website at http://water.usgs.gov/osw/flood_inundation.

[b] The CharlemontMA_11 map has an annual exceedance probability of 1 percent and thus approximately depicts the tropical storm Irene flood of August 28, 2011, at this streamgage.

Development of Flood-Inundation Maps

Flood-inundation maps were created in a GIS for the 15 water-surface profiles of the upstream reach (upstream of the North River tributary, Charlemont streamgage, table 8) and the 17 water-surface profiles of the downstream reach (downstream of the North River tributary, West Deerfield streamgage, table 9) by combining the profiles and DEM data. The maps depict the flood plain boundaries of the 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent AEP floods and of the tropical storm Irene flood of August 28, 2011, which had an AEP of 1-percent at the Charlemont streamgage and 0.5-percent at the West Deerfield streamgage.

The DEM data were derived from the lidar data described in the “Topographic and Bathymetric Data” section and have an estimated vertical accuracy of 1 ft. Estimated flood-inundation boundaries for each simulated profile were developed with HEC–GeoRAS, which allows the preparation of geometric data for import into HEC–RAS and processes simulation results exported from HEC–RAS. Shapefile polygons and depth grids of the inundated areas for each profile were modified in the ArcMap application of Esri ArcGIS to ensure a hydraulically reasonable transition of the flood boundaries between modeled cross sections.

The flood-inundation areas are overlaid on high-resolution, geospatially referenced, aerial photographs of the study area (fig. 3). Any inundated areas that were detached from the main channel were examined to identify subsurface connections with the main river, such as through culverts under roadways. Where such connections existed, the mapped inundated areas were retained in their respective flood maps; otherwise, the erroneously delineated parts of the flood extent were deleted. Bridge surfaces are shown as not inundated up to the lowest flood stage that either intersects the lowest structural chord of the bridge or completely inundates one or both approaches to the bridge. In these latter circumstances, the bridge surface is depicted as being inundated. A shaded building should not be interpreted to mean that the structure is completely submerged, but rather that bare-earth surfaces in the vicinity of the building are inundated. In these instances, the water depth (as indicated in the mapping application by holding the cursor over an inundated area) near the building would be an estimate of the water level inside the structure, unless flood-proofing measures had been implemented. Estimates of water depth can be obtained from the depth-grid data that are included with the presentation of the flood maps on an interactive USGS mapping application described in the “Flood-Inundation Map Delivery” section.

Table 9. Stage, elevation, discharge, and annual exceedance probabilities at the Deerfield River near West Deerfield, MA streamgage (01170000) for inundated areas mapped on the Deerfield River in Franklin County, Massachusetts.

[Streamgage is shown in figure 1 and described in table 2. ft, foot; NAVD 88, North American Vertical Datum of 1988; ft³/s, cubic foot per second; NA, not applicable]

Grid identification[a]	Stage at 01170000, in ft	Elevation at 01170000, in ft above NAVD 88	Discharge at 01170000, in ft³/s	Annual exceedance probability, in percent
WDeerfieldMA_01	8.5	165.2	16,100	50
WDeerfieldMA_02	9.6	166.3	20,700	NA
WDeerfieldMA_03	10.8	167.5	25,400	20
WDeerfieldMA_04	12.6	169.3	33,500	10
WDeerfieldMA_05	14.0	170.7	39,800	NA
WDeerfieldMA_06	15.3	172.0	46,500	4
WDeerfieldMA_07	16.5	173.2	52,100	NA
WDeerfieldMA_08	17.7	174.4	58,600	2
WDeerfieldMA_09	19.1	175.8	65,600	NA
WDeerfieldMA_10	20.5	177.2	73,000	1
WDeerfieldMA_11	22.2	178.9	81,500	NA
WDeerfieldMA_12 [b]	23.8	180.5	90,200	0.5
WDeerfieldMA_13	25.0	181.7	96,300	NA
WDeerfieldMA_14	26.0	182.7	101,700	NA
WDeerfieldMA_15	27.0	183.7	107,200	NA
WDeerfieldMA_16	28.0	184.7	112,700	NA
WDeerfieldMA_17	29.0	185.7	118,100	0.2

[a] Grids refer to flood inundation maps on the U.S. Geological Survey flood inundation mapping website at http://water.usgs.gov/osw/flood_inundation.

[b] The WDeerfieldMA_12 map has an annual exceedance probability of 0.5 percent and thus approximately depicts the tropical storm Irene flood of August 28, 2011, at this streamgage.

Flood-Inundation Map Delivery

A flood-inundation mapping science Web site (http://water.usgs.gov/osw/flood_inundation) has been established to make USGS flood-inundation study information available to the public. This Web site links to the Flood Inundation Mapper, a mapping application that presents map libraries and provides detailed information on flood extents and depths for modeled sites in the United States. The mapping application enables the production of customized flood-inundation maps from the map library through a print-on-demand feature that allows the user to zoom to the area of interest, choose the desired stage, and print only that part of the map (fig. 3). The flood-inundation maps are displayed in sufficient detail so that preparations for flooding and decisions for emergency response can be done efficiently.

The upstream and downstream reaches in this report are presented on the USGS flood-inundation Web site as two separate flood libraries, each linked to the streamgage within their respective reaches. It cannot be assumed that a stage at one of the streamgages will result in a known stage at the other streamgage, so the two reaches are selected and viewed independently of one another within the flood-inundation mapping Web site. The Flood Inundation Mapper links to the USGS National Water Information System (NWIS) page for each of the streamgages (U.S. Geological Survey, 2014a,b) shown on the map that presents the current (real-time) stage and streamflow at the West Deerfield and Charlemont streamgages to which the inundation maps are referenced. Shapefiles depicting flood plain boundaries for the 1- and 0.2- percent AEP floods are available through links presented in appendix 2.

Disclaimer for Flood-inundation Maps

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

Uncertainties and Limitations Regarding Use of Flood-Inundation Maps

Although the flood-inundation maps represent the boundaries of inundated areas with a distinct line, some uncertainty is associated with these maps. There are uncertainties associated with the hydrology, the model, the observed

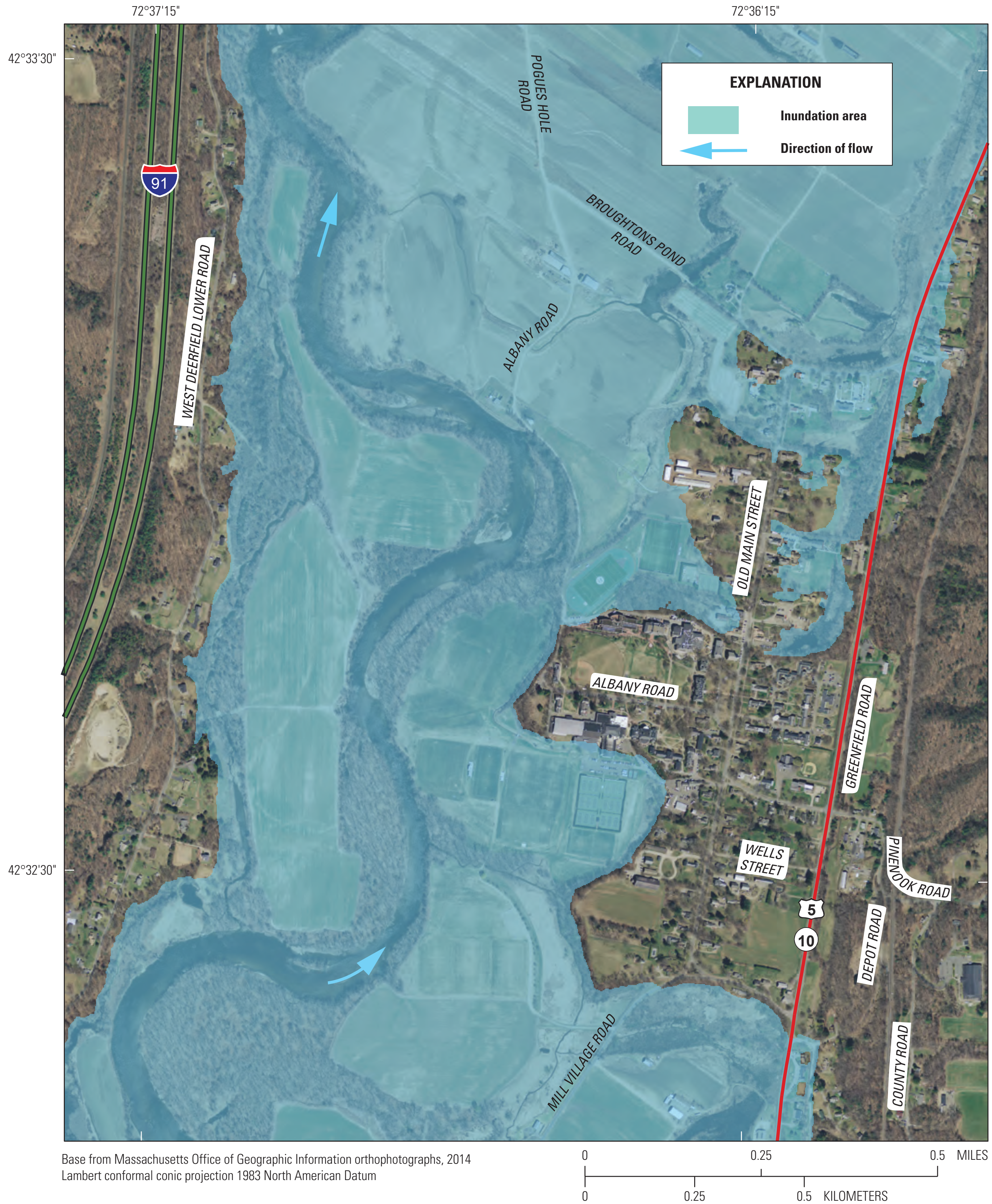

Figure 3. Flood inundation for a region on the Deerfield River near Deerfield, Massachusetts, corresponding to a stage of 23.8 ft (approximately the 0.5 percent annual exceedance probability flood) and approximately depicts the August 28, 2011, tropical storm Irene peak flow at the U.S. Geological streamgage Deerfield River near West Deerfield, MA (01170000).

water surfaces, and the mapping. The flood boundaries shown were estimated on the basis of flood stages and streamflows at the West Deerfield and Charlemont streamgages. There are errors associated with the stage-discharge rating curves used to estimate flow at the streamgages, as the rating curve is a smoothed line through the streamflow measurements and the concurrent stage. Uncertainties associated with the peak flow analyses used to estimate flood flows with given annual exceedance probabilities are shown in table 3. They are shown by the variances and the 95-percent lower and upper confidence intervals. Estimates of flow are computed upstream and downstream from the streamgages using the estimates of flows at the streamgage and then adjusting them for the change in drainage area from the streamgage to the new location. Meteorological factors such as the timing and distribution of precipitation may cause actual streamflows along the modeled reach to vary from those assumed during a flood, which may lead to deviations in the water-surface elevations and inundation boundaries shown.

Water-surface elevations along the stream reaches were estimated by steady-state hydraulic modeling, assuming unobstructed flow and using streamflows and hydrologic conditions anticipated at the streamgage. The hydraulic model reflects the land-cover characteristics and any bridge, dam, levee, or other hydraulic structures existing as of the surveying in September through December 2012 and August through December 2013. HEC–RAS is a one-dimensional model and as such, cannot always capture what is occurring in the drainage area of the stream. Additional areas may be flooded because of unanticipated conditions, such as changes in the streambed elevation or roughness, backwater into major tributaries along a main stem river, or backwater from localized debris. HEC–RAS models are more accurate when they are calibrated to flows from streamgages and to high water marks collected after flooding events. Thus the models are as good as the data to which they are calibrated.

High-water marks collected in the field are from actual events and are given a rating from poor (plus or minus 0.2 ft) to excellent (plus or minus 0.05 ft) at the time they are collected. Ratings often reflect the quality of the mark itself and do not always get at when the mark occurred during a storm. For example, a HWM rated excellent could have been made during the recession of the flood—in which case it could be off more than 0.2 ft. In addition, high flows can be extremely turbulent, causing additional error and uncertainty in the HMWs (fig. 2). Table 7 shows the difference between the high-water marks surveyed from the tropical storm Irene flood flows and the modeled water-surface. This gives a general indication of the uncertainty in the model.

The accuracy of the floodwater extent portrayed on these maps will also vary with the accuracy of the DEM used to simulate the land surface. Not all of the sources of error can be quantified, and so caution should be used when using the final water surface elevations and maps

Summary

Two sets of digital flood-inundation maps were developed by the U.S. Geological Survey (USGS) in cooperation with the Federal Emergency Management Agency (FEMA) for sections of the 30-mile reach of the Deerfield River. The set of 15 maps associated with the upstream 9.1-mile (mi) section of the reach are linked to the Deerfield River at Charlemont, MA (01168500) streamgage and cover an area that extends from just downstream of the Cold River tributary to upstream of the Clesson Brook tributary. The set of 17 maps associated with the downstream 8.9-mi section of the reach are linked to the Deerfield River near West Deerfield, MA (01170000) streamgage and cover an area that extends from just downstream of the confluence with the South River tributary to just upstream of the confluence with the Green River tributary. The maps were developed by using the U.S. Army Corps of Engineers HEC–RAS and HEC–GeoRAS programs to compute water-surface profiles and to delineate estimated flood-inundation areas and depths of flooding for selected stages. The HEC–RAS hydraulic model was calibrated to the current [2015] stage-discharge relations at the two USGS Deerfield River streamgages and to the peak water-surface elevations (high-water marks) along the 30-mi reach from the August 28, 2011, flood of tropical storm Irene.

The hydraulic model was used to compute 15 stages for mapped profiles of the upstream (western) reach ranging from 8.7 feet (ft; 525.6 ft at NAVD 88) to 25.7 ft (542.6 ft at NAVD 88) at the Charlemont (01168500) streamgage and 17 stages for mapped profiles of the downstream (eastern) reach ranging from 8.5 ft (165.2 ft at NAVD 88) to 29.0 ft (185.7 ft at NAVD 88) at the West Deerfield (01170000) streamgage. Modeled water-surface profiles correspond to floods with 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent annual exceedance probabilities (AEPs) and to the August 28, 2011, flood, making them consistent with FEMA flood recovery maps for the 1- and 0.2-percent AEPs. Additional stages were mapped when the gap between the stages corresponding to the AEP floods exceeded 2 ft.

Water-surface profiles were combined with a geographic information system (GIS) digital elevation model derived from light detection and ranging (lidar) data to delineate estimated flood-inundation areas as shapefile polygons and depth grids for each profile. These flood-inundation polygons were overlaid on high-resolution, geospatially referenced aerial photographs of the study area. The flood maps are available through a mapping application that can be accessed on the USGS flood-inundation mapping science Web site (http://water.usgs.gov/osw/flood_inundation/) or as static maps in this report. Interactive use of the maps on the USGS mapping application can give users a general indication of water depth at any point by using the mouse cursor to click within the shaded areas. These maps, in conjunction with the real-time stage data from the Charlemont and West Deerfield streamgages, can help guide the general public in taking individual safety precautions and can provide emergency management personnel with a tool to

efficiently manage emergency flood operations and postflood recovery efforts. The flood-inundation maps are nonregulatory, but provide Federal, State, and local agencies and the public with estimates of the potential extent of flooding during selected peak-flow events.

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Appendixes

Appendix 1. Water-Surface Elevations at Modeled Cross Sections Along the Deerfield River, Franklin County, Massachusetts

Appendix 2. Area of Flood Inundation for the 1- and 0.2-Percent Annual Exceedance Probability Flows Along the Deerfield River Study Reach in Franklin County, Massachusetts

[Shapefiles available at http://dx.doi.org/10.3133/sir20155104.]

Appendix 1. Water-Surface Elevations at Modeled Cross Sections Along the Deerfield River, Franklin County, Massachusetts

Table 1–1. Water-surface elevations for the 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent annual exceedance probability (AEP) floods, the August 28, 2011, flood, and the 1-percent AEP floodway at modeled cross sections of the Deerfield River in Franklin County, Massachusetts, from the confluence of the Cold River tributary in Charlemont to the Connecticut River at the town boundary of Deerfield and Greenfield.

[Cross-section identification numbers (IDs) are referenced to the longitudinal baseline used in the hydraulic model starting at the most downstream point in the model. Floodway is the channel of a river and the adjacent flood plain that must be kept free of encroachment so that the base flood (1-percent [%] AEP flood) can be conveyed without increasing the water-surface elevation more than 1 foot (ft). NAVD 88, North American Vertical Datum of 1988]

Cross-section ID, in ft[a]	Water-surface elevation, in ft above NAVD 88								
	AEP								1% AEP floodway
	50%	20%	10%	4%	2%	1%[b]	0.5%[c]	0.2%	
158,998	589.13	591.62	593.29	595.69	597.92	600.37	604.68	606.33	600.37
158,527	587.78	590.17	591.72	594.23	596.81	599.51	604.23	605.49	599.51
158,374	587.00	589.23	590.82	593.32	595.90	598.46	603.52	604.38	598.45
158,293	586.37	588.13	589.20	590.32	590.54	592.10	593.77	596.09	592.11
158,173	585.56	587.06	588.00	588.99	589.84	591.24	592.65	594.58	591.24
157,251	582.24	583.89	585.09	586.55	587.73	589.13	590.68	593.04	589.50
155,827	575.94	578.30	579.86	581.89	583.44	585.16	586.95	589.11	585.21
153,480	568.41	570.41	571.77	573.33	574.66	576.06	577.58	579.58	576.37
153,255	568.31	570.44	571.94	572.87	574.18	575.56	577.11	579.09	575.92
153,119	567.34	569.12	570.37	571.69	572.74	573.73	574.72	576.22	574.34
152,752	566.22	568.02	569.12	570.52	571.55	572.66	573.81	575.62	573.65
151,351	563.32	565.20	566.32	567.79	568.89	570.11	571.35	573.34	570.34
149,703	559.07	560.90	562.06	563.53	564.63	566.00	566.99	568.46	566.89
149,236	557.79	559.54	560.74	562.30	563.49	565.02	565.81	567.40	565.53
146,736	548.53	550.96	552.48	554.56	556.12	557.13	558.62	560.66	558.06
144,321	545.10	546.90	548.43	550.37	551.78	554.06	555.66	558.11	554.08
144,198	545.16	546.91	548.46	550.41	551.83	553.57	555.71	558.15	554.13
144,149	545.08	546.75	548.24	550.09	551.41	553.06	555.62	558.39	553.91
143,693	543.36	545.32	546.77	548.90	550.54	552.36	554.16	556.87	552.83
142,033	538.89	541.40	543.33	545.96	548.04	550.03	552.20	555.31	550.86
141,216	536.61	539.32	541.36	544.13	546.52	548.66	550.98	554.21	548.82
140,766	535.45	538.02	539.86	542.32	544.19	546.22	548.31	551.44	546.39
138,058	528.48	530.99	532.82	535.35	537.36	539.58	541.98	545.48	540.35
136,257	524.89	527.54	529.47	532.14	534.25	536.58	539.01	542.62	537.55
134,567	522.04	524.69	526.63	529.29	531.39	533.61	536.01	539.65	534.61
132,834	518.30	520.87	522.80	525.50	527.66	530.02	532.56	536.35	530.18
131,279	514.55	517.43	519.54	522.42	524.67	527.10	529.67	533.30	527.10
128,662	508.85	511.45	513.25	515.63	517.44	519.37	521.37	524.17	519.37
126,621	505.08	506.93	508.35	510.37	512.03	513.72	515.43	517.59	513.74
124,886	500.55	503.00	504.92	507.58	509.70	511.64	513.62	516.45	511.66
122,961	496.58	499.20	501.05	503.48	505.43	507.25	509.23	512.02	507.25
120,756	492.25	494.85	496.70	499.13	501.00	503.07	505.22	508.53	503.07

Table 1–1. Water-surface elevations for the 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent annual exceedance probability (AEP) floods, the August 28, 2011, flood, and the 1-percent AEP floodway at modeled cross sections of the Deerfield River in Franklin County, Massachusetts, from the confluence of the Cold River tributary in Charlemont to the Connecticut River at the town boundary of Deerfield and Greenfield.—Continued

[Cross-section identification numbers (IDs) are referenced to the longitudinal baseline used in the hydraulic model starting at the most downstream point in the model. Floodway is the channel of a river and the adjacent flood plain that must be kept free of encroachment so that the base flood (1-percent [%] AEP flood) can be conveyed without increasing the water-surface elevation more than 1 foot (ft). NAVD 88, North American Vertical Datum of 1988]

Cross-section ID, in ft[a]	Water-surface elevation, in ft above NAVD 88								
	AEP								1% AEP floodway
	50%	20%	10%	4%	2%	1%[b]	0.5%[c]	0.2%	
118,590	489.77	492.21	493.93	496.07	497.70	499.42	500.77	502.55	499.42
116,928	487.00	488.96	490.30	491.85	493.00	494.35	495.82	498.28	494.37
114,965	482.14	484.15	485.63	487.80	489.77	491.84	493.60	496.71	492.01
113,294	478.29	480.35	481.98	484.39	486.59	488.73	490.08	493.54	489.10
110,931	474.74	477.52	479.64	482.56	485.10	487.35	489.86	493.54	487.52
108,703	471.85	474.82	477.01	479.95	482.57	484.58	487.06	490.48	484.69
107,049	470.17	473.25	475.50	478.55	481.39	483.36	485.92	489.46	483.41
105,235	468.32	471.01	473.02	475.81	478.91	480.43	482.88	486.24	480.43
104,904	468.12	470.80	472.86	475.72	478.93	480.52	483.06	486.53	480.51
104,848	467.90	470.49	472.43	475.25	478.53	480.04	482.59	486.03	480.04
104,684	467.66	470.14	472.08	474.78	478.02	479.31	481.72	484.96	479.31
104,499	467.39	469.81	471.74	474.46	477.81	479.07	481.53	484.87	479.07
104,233	467.43	469.85	471.76	474.44	477.75	478.98	481.37	484.69	478.97
104,125	442.52	444.89	446.63	449.09	450.96	452.94	454.95	457.73	452.98
103,761	436.68	438.84	440.48	442.64	444.25	445.94	447.63	450.35	446.64
103,281	434.43	436.32	437.66	439.58	441.22	443.10	445.25	448.57	443.55
102,356	427.18	429.83	431.73	434.43	436.64	439.06	441.67	445.46	439.24
100,553	421.48	424.63	426.90	429.99	432.41	434.97	437.70	441.69	435.12
99,755	419.05	421.81	423.77	426.47	428.63	430.87	433.39	436.51	431.26
98,494	416.37	419.07	421.05	423.77	425.99	428.37	431.33	435.04	428.91
97,565	414.20	416.93	418.90	421.60	423.76	426.09	429.25	432.47	427.09
95,975	410.97	413.62	415.56	418.25	420.45	422.82	426.68	429.68	423.34
94,300	407.70	410.41	412.45	415.21	417.45	419.90	424.63	427.25	420.24
93,847	407.28	410.05	412.16	415.08	417.46	420.04	424.58	427.28	420.08
93,777	407.03	409.75	411.83	414.72	417.08	419.65	424.28	426.87	419.70
93,333	405.76	408.36	410.29	412.98	415.16	417.49	422.85	424.64	417.81
91,329	403.47	405.97	407.84	410.48	412.61	414.90	421.30	422.47	415.20
90,699	403.04	405.45	407.27	409.83	411.91	414.15	421.09	422.29	414.49
90,258	402.75	405.17	407.03	409.67	411.82	414.04	421.03	422.26	414.49
90,228	402.33	404.50	406.17	408.51	410.38	412.66	418.55	419.91	412.82
90,175	402.31	404.47	406.08	408.25	409.83	411.66	418.30	419.56	411.80
90,120	402.22	404.37	405.98	408.13	409.69	411.49	417.91	418.84	411.63
90,068	402.02	404.07	405.62	407.68	409.24	410.04	411.35	413.12	410.25
89,796	401.47	403.45	404.94	406.90	408.24	409.53	410.80	412.51	409.78
89,329	401.52	403.52	405.04	407.02	408.38	409.71	411.02	412.82	409.95

Table 1–1. Water-surface elevations for the 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent annual exceedance probability (AEP) floods, the August 28, 2011, flood, and the 1-percent AEP floodway at modeled cross sections of the Deerfield River in Franklin County, Massachusetts, from the confluence of the Cold River tributary in Charlemont to the Connecticut River at the town boundary of Deerfield and Greenfield.—Continued

[Cross-section identification numbers (IDs) are referenced to the longitudinal baseline used in the hydraulic model starting at the most downstream point in the model. Floodway is the channel of a river and the adjacent flood plain that must be kept free of encroachment so that the base flood (1-percent [%] AEP flood) can be conveyed without increasing the water-surface elevation more than 1 foot (ft). NAVD 88, North American Vertical Datum of 1988]

Cross-section ID, in ft[a]	Water-surface elevation, in ft above NAVD 88								
	AEP								1% AEP floodway
	50%	20%	10%	4%	2%	1%[b]	0.5%[c]	0.2%	
89,289	384.58	386.04	387.11	388.62	389.84	391.20	392.61	394.69	391.20
88,700	350.38	353.05	354.98	357.18	358.75	360.39	362.19	365.01	360.39
87,552	343.15	345.18	346.56	348.30	349.80	351.51	353.37	356.13	351.52
87,244	339.96	341.70	343.03	345.33	347.18	349.15	351.16	353.94	349.25
85,551	337.46	339.50	341.34	343.16	344.83	346.64	348.33	350.47	346.86
84,179	337.21	339.13	340.95	342.68	344.31	346.13	347.81	349.93	346.35
83,904	337.15	339.03	340.83	342.50	344.08	345.83	347.55	349.63	346.06
83,857	323.61	325.13	326.26	327.91	329.26	330.80	332.45	335.10	330.80
83,539	313.62	315.64	317.27	319.44	321.18	324.29	326.42	329.64	324.60
82,223	297.70	300.91	303.20	306.39	308.96	311.66	314.57	318.65	312.27
80,105	294.11	297.33	299.68	302.96	305.61	308.31	311.17	315.31	308.64
77,603	292.68	295.52	297.61	300.53	302.86	305.16	307.55	310.92	305.33
75,529	291.55	293.99	295.80	298.40	300.51	302.53	304.61	307.56	302.54
74,315	291.28	293.64	295.42	298.00	300.10	302.12	304.22	307.22	302.12
73,729	291.21	293.54	295.29	297.84	299.92	301.90	303.93	306.80	301.90
73,639	239.83	243.54	246.18	249.81	252.73	255.87	259.24	264.12	255.92
73,319	238.84	242.34	244.81	248.19	250.91	253.85	257.03	261.60	253.92
72,397	233.76	236.71	238.69	241.26	243.16	245.06	246.93	249.63	245.24
69,214	216.32	219.21	221.28	224.16	226.50	228.99	231.67	235.69	228.99
67,131	207.17	209.54	211.37	214.00	216.18	218.53	221.08	224.77	219.34
65,156	198.48	201.50	203.65	206.58	208.91	211.25	213.76	217.45	211.54
63,334	194.99	197.88	199.88	202.64	204.89	207.29	209.93	214.03	207.38
62,837	193.18	195.76	197.61	200.22	202.37	204.82	207.61	212.08	204.96
62,775	192.90	195.42	197.21	199.77	201.86	204.25	206.99	211.43	204.43
62,279	187.83	190.37	192.47	195.63	198.21	200.99	204.05	208.88	201.31
61,081	183.48	186.94	189.48	193.07	195.84	198.80	202.07	207.23	199.20
60,757	182.13	185.34	187.62	190.78	193.19	195.73	198.59	203.36	196.35
60,730	180.90	183.60	185.42	187.89	190.33	192.91	195.33	199.64	193.74
60,553	181.41	184.40	186.44	189.18	191.36	193.65	196.04	199.40	194.43
58,849	179.37	181.90	183.69	186.13	188.14	190.29	192.61	196.00	190.95
56,831	175.18	177.88	179.87	182.65	184.96	187.45	190.17	194.20	188.13
55,005	172.22	174.92	176.91	179.63	181.82	184.10	186.56	190.20	184.39
54,832	171.90	174.62	176.64	179.39	181.61	183.92	186.43	190.13	184.36
52,818	169.06	171.70	173.67	176.40	178.63	181.02	183.64	187.52	181.73
52,265	168.20	170.97	173.00	175.80	178.09	180.52	183.20	187.15	181.16

Table 1–1. Water-surface elevations for the 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent annual exceedance probability (AEP) floods, the August 28, 2011, flood, and the 1-percent AEP floodway at modeled cross sections of the Deerfield River in Franklin County, Massachusetts, from the confluence of the Cold River tributary in Charlemont to the Connecticut River at the town boundary of Deerfield and Greenfield.—Continued

[Cross-section identification numbers (IDs) are referenced to the longitudinal baseline used in the hydraulic model starting at the most downstream point in the model. Floodway is the channel of a river and the adjacent flood plain that must be kept free of encroachment so that the base flood (1-percent [%] AEP flood) can be conveyed without increasing the water-surface elevation more than 1 foot (ft). NAVD 88, North American Vertical Datum of 1988]

Cross-section ID, in ft[a]	Water-surface elevation, in ft above NAVD 88								
	AEP								1% AEP floodway
	50%	20%	10%	4%	2%	1%[b]	0.5%[c]	0.2%	
50,998	166.45	169.19	171.18	173.98	176.29	178.78	181.51	185.54	179.55
50,759	166.08	168.80	170.77	173.57	175.88	178.38	181.12	185.17	179.15
50,486	165.22	167.90	169.86	172.64	174.94	177.42	180.13	184.15	177.75
50,342	164.82	167.57	169.55	172.36	174.69	177.20	179.95	184.01	177.75
48,756	161.35	164.23	166.27	169.11	171.43	173.90	176.59	180.54	174.40
46,525	157.69	160.99	163.24	166.33	168.80	171.40	174.22	178.35	171.87
44,195	155.99	158.91	160.85	163.48	165.58	167.77	170.11	173.48	168.38
42,686	155.08	157.93	159.82	162.42	164.54	166.82	169.29	172.95	167.28
42,358	154.22	156.91	158.63	160.94	162.81	164.82	166.97	170.14	165.42
42,315	154.00	156.58	158.17	160.28	161.95	163.71	165.56	168.18	164.60
41,800	152.15	154.21	155.48	157.09	158.36	159.65	160.98	162.86	160.60
40,706	149.23	151.99	153.26	154.66	155.82	157.11	158.52	160.74	157.73
40,092	148.28	151.20	152.58	154.03	155.26	156.64	158.14	160.47	156.65
39,799	148.02	150.99	152.49	153.97	155.19	156.55	158.04	160.33	156.94
38,887	143.90	146.71	148.24	150.25	151.75	153.24	154.47	156.32	153.73
37,404	143.63	145.96	147.23	148.72	149.88	151.07	151.65	153.60	151.56
36,937	143.03	145.25	146.44	147.78	148.81	149.81	150.78	153.03	150.61
34,793	139.07	141.57	143.17	144.95	145.91	146.67	148.02	151.77	147.68
32,881	135.95	138.00	139.06	140.34	141.67	143.64	146.43	151.15	144.50
31,271	134.81	136.82	138.13	139.84	141.30	143.25	146.09	150.99	144.24
29,498	133.53	135.64	137.11	139.00	140.59	142.71	145.78	150.84	143.70
27,362	131.95	134.31	135.92	137.96	139.68	142.03	145.32	150.54	142.93
26,311	131.44	133.86	135.46	137.52	139.26	141.67	145.03	150.33	142.60
24,850	130.51	133.12	134.81	136.94	138.76	141.29	144.76	150.17	142.19
22,639	128.59	131.53	133.38	135.89	138.02	140.80	144.46	150.03	141.70
21,054	127.83	130.97	132.88	135.50	137.73	140.61	144.35	149.97	141.45
19,621	126.98	129.96	131.70	134.28	136.94	140.29	144.21	149.90	141.05
18,308	126.11	129.13	131.09	134.10	136.94	140.26	144.18	149.88	141.02
16,268	124.80	127.95	130.26	133.65	136.71	140.13	144.11	149.84	140.88
13,679	123.61	127.27	129.75	133.30	136.49	139.98	144.01	149.77	140.74
13,089	123.42	127.05	129.51	133.15	136.4	139.92	143.98	149.75	140.68
10,538	122.45	126.35	129.06	132.89	136.21	139.79	143.88	149.68	140.54
10,386	122.44	126.32	129.04	132.87	136.2	139.79	143.88	149.68	140.52
7,298	121.47	125.48	128.33	132.33	135.77	139.45	143.61	149.46	140.18
6,494	120.76	124.65	127.53	131.67	135.25	139.05	143.29	149.16	139.68

Table 1–1. Water-surface elevations for the 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent annual exceedance probability (AEP) floods, the August 28, 2011, flood, and the 1-percent AEP floodway at modeled cross sections of the Deerfield River in Franklin County, Massachusetts, from the confluence of the Cold River tributary in Charlemont to the Connecticut River at the town boundary of Deerfield and Greenfield.—Continued

[Cross-section identification numbers (IDs) are referenced to the longitudinal baseline used in the hydraulic model starting at the most downstream point in the model. Floodway is the channel of a river and the adjacent flood plain that must be kept free of encroachment so that the base flood (1-percent [%] AEP flood) can be conveyed without increasing the water-surface elevation more than 1 foot (ft). NAVD 88, North American Vertical Datum of 1988]

Cross-section ID, in ft[a]	Water-surface elevation, in ft above NAVD 88								
	AEP								1% AEP floodway
	50%	20%	10%	4%	2%	1%[b]	0.5%[c]	0.2%	
5,893	120.66	124.66	127.51	131.52	134.92	138.54	142.61	148.28	139.28
5,832	120.58	124.54	127.29	131.15	134.38	137.81	141.65	147.99	138.67
5,737	120.58	124.56	127.38	131.35	134.69	138.22	142.17	148.06	138.93
5,651	120.52	124.50	127.30	131.22	134.54	138.05	141.97	147.79	138.89
5,605	120.43	124.36	127.17	131.19	134.53	138.07	142.03	148.03	138.96
5,540	120.28	124.17	126.93	130.80	134.06	137.51	141.36	147.00	138.13
5,448	119.96	123.82	126.60	130.50	133.76	137.19	141.03	146.77	138.06
5,111	120.15	124.00	126.75	130.61	133.83	137.23	141.02	146.70	138.02
3,293	119.39	123.07	125.71	129.44	132.57	135.88	139.60	145.16	136.73
2,240	118.68	122.31	124.95	128.71	131.89	135.23	138.99	144.58	136.14
1,991	118.35	121.89	124.43	128.02	131.04	134.24	137.85	143.27	134.92
1,926	117.97	121.41	123.89	127.48	130.55	133.80	137.45	142.94	133.82
1,618	117.93	121.48	124.02	127.65	130.72	133.95	137.55	142.84	134.67
637	117.31	120.83	123.36	126.97	130.04	133.29	136.92	142.25	133.98

[a]Cross-section identification numbers are referenced to the longitudinal baseline used in the hydraulic model starting at the most downstream point in the model.

[b]For the Charlemont streamgage (cross section IDs 158,998 through 99,755), the 1% AEP flood approximately depicts the August 28, 2011, flood.

[c]For the West Deerfield streamgage (cross section IDs 98,494 through 32,881), the 0.5% AEP flood approximately depicts the August 28, 2011, flood.

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