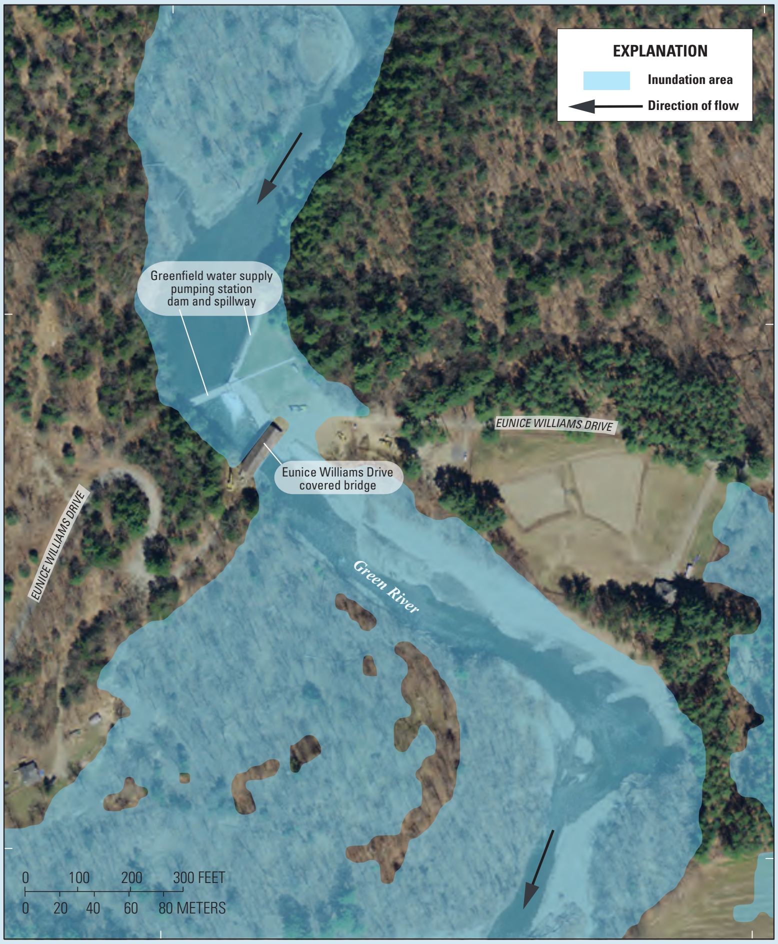
Prepared in cooperation with the Federal Emergency Management Agency

Flood-Inundation Maps for the Green River in Colrain, Leyden, and Greenfield, Massachusetts, From U.S. Geological Survey Streamgage 01170100 Green River Near Colrain to the Confluence With the Deerfield River



Scientific Investigations Report 2016–5107

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Cover. Map showing flood inundation for a downstream region on the Green River study reach, corresponding to a stage of 14.4 feet at the U.S. Geological Survey streamgage Green River near Colrain, Massachusetts (01170100).

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By Robert H. Flynn, Gardner C. Bent, and Pamela J. Lombard

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Contents

Figures

Tables

Conversion Factors

U.S. Customary Units to International System of Units

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

Datum

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

AEP	annual exceedance probability
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
RTK	real-time kinematic
USGS	U.S. Geological Survey

Flood-Inundation Maps for the Green River in Colrain, Leyden, and Greenfield, Massachusetts, From U.S. Geological Survey Streamgage 01170100 Green River Near Colrain to the Confluence With the Deerfield River

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Abstract

The U.S. Geological Survey developed flood elevations in cooperation with the Federal Emergency Management Agency for a 14.3-mile reach of the Green River in Colrain, Leyden, and Greenfield, Massachusetts, to assist landowners and emergency management workers to prepare for and recover from floods. The river reach extends from the U.S. Geological Survey Green River near Colrain, MA (01170100) streamgage downstream to the confluence with the Deerfield River. A series of seven digital flood inundation maps were developed for the upper 4.4 miles of the river reach downstream from the stream. Flood discharges corresponding to the 50-, 10-, 1-, and 0.2-percent annual exceedance probabilities were computed for the reach from updated flood-frequency analyses. These peak flows and the flood flows associated with the stages of 10.2, 12.4, and 14.4 feet (ft) at the Green River streamgage 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 (stage 13.97 ft), into historical context. The hydraulic model was calibrated by using the current (2015) stage-discharge relation at the U.S. Geological Survey Green River near Colrain, MA (01170100) streamgage and from documented high-water marks from the Tropical Storm Irene flood, which had a flow higher than a 0.2-percent annual exceedance probability flood discharge.

The hydraulic model was used to compute water-surface profiles for flood stages referenced to the streamgage and ranging from the 50-percent annual exceedance probability (bankfull flow) at 7.6 ft (439.8 ft above the North American Vertical Datum of 1988 [NAVD 88]) to 14.4 ft (446.7 ft NAVD 88), which exceeds the maximum recorded water level of 13.97 ft (Tropical Storm Irene) at the streamgage. The mapped stages of 7.6 to 14.4 ft were selected to match the stages for bankfull; the 50-, 10-, 1-, and 0.2-percent annual exceedance probabilities; incremental stages of 10.2 and 12.4 ft; and the maximum stage of the stage-discharge rating curve. The simulated water-surface profiles were combined with a geographic information system digital elevation model derived from light detection and ranging (lidar) data having a 0.5-ft vertical accuracy to create a set of flood-inundation maps.

The availability of the flood-inundation maps, combined with information regarding near real-time stage from U.S. Geological Survey Green River near Colrain, MA (01170100) streamgage, can provide emergency management personnel and residents with information that is critical for flood response activities, such as evacuations and road closures, 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.

Introduction

On August 22, 2011, Hurricane Irene traveled 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 for U.S. Geological Survey (USGS) streamgages that had been in operation for decades. 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).

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. The peak flow of 13,200 cubic feet per second (ft^3/s) at USGS Green River near Colrain, MA (01170100) streamgage (fig. 1, hereafter referred to as the Green River streamgage) is greater than the 0.2-percent AEP flood of 12,100 ft^3/s at the streamgage. The peak flow of 13,200 ft^3/s at the Green River streamgage was determined from the current (2015) stage-discharge relation (rating curve), which was extended based on discharge determined from indirect flow estimation techniques (Dalrymple and Benson, 1967; Matthai, 1967; Fulford, 1994; Bradley, 2012) and the stage of the peak. The USGS North River at Shattuckville, MA (01169000) streamgage (not shown; U.S. Geological Survey, 2014a) in the adjacent basin to the west of the Green River (fig. 1) had a peak discharge of 30,300 ft^3/s, which is roughly equivalent to the 0.2-percent AEP flood of 30,400 ft^3/s at the USGS North River at Shattuckville, MA (01169000) streamgage. The peak flows at the North River streamgage were determined from the current (2015) stage-discharge relation (rating curve), which was extended based on discharge determined from indirect flow estimation techniques (Matthai, 1967).

The town of Greenfield estimated damages from Tropical Storm Irene of $11 million, mainly to the infrastructure of the town (Stabile, 2011). Damages to infrastructure in Greenfield included the washout of Eunice Williams Drive at a historic covered bridge (fig. 1), which was caused by the upstream failure of a segment of the dam for the Greenfield water supply pumping station. The Greenfield Green River Swimming and Recreation Area (fig. 1) near the midpoint of the stream reach had extensive damage due to flooding, and the wastewater treatment facility (not shown) of the town along the Green River near its confluence with the Deerfield River was partially flooded. Additionally, damage occurred to several private homes and businesses; for example, a private home was destroyed just upstream from West Leyden Road on the border between the towns of Colrain and Leyden, a business on the downstream side of Colrain Road in Greenfield was flooded, and the first floor of the Museum of Our Industrial Heritage on the downstream side of Mill Street and River Street in Greenfield was flooded (fig. 1).

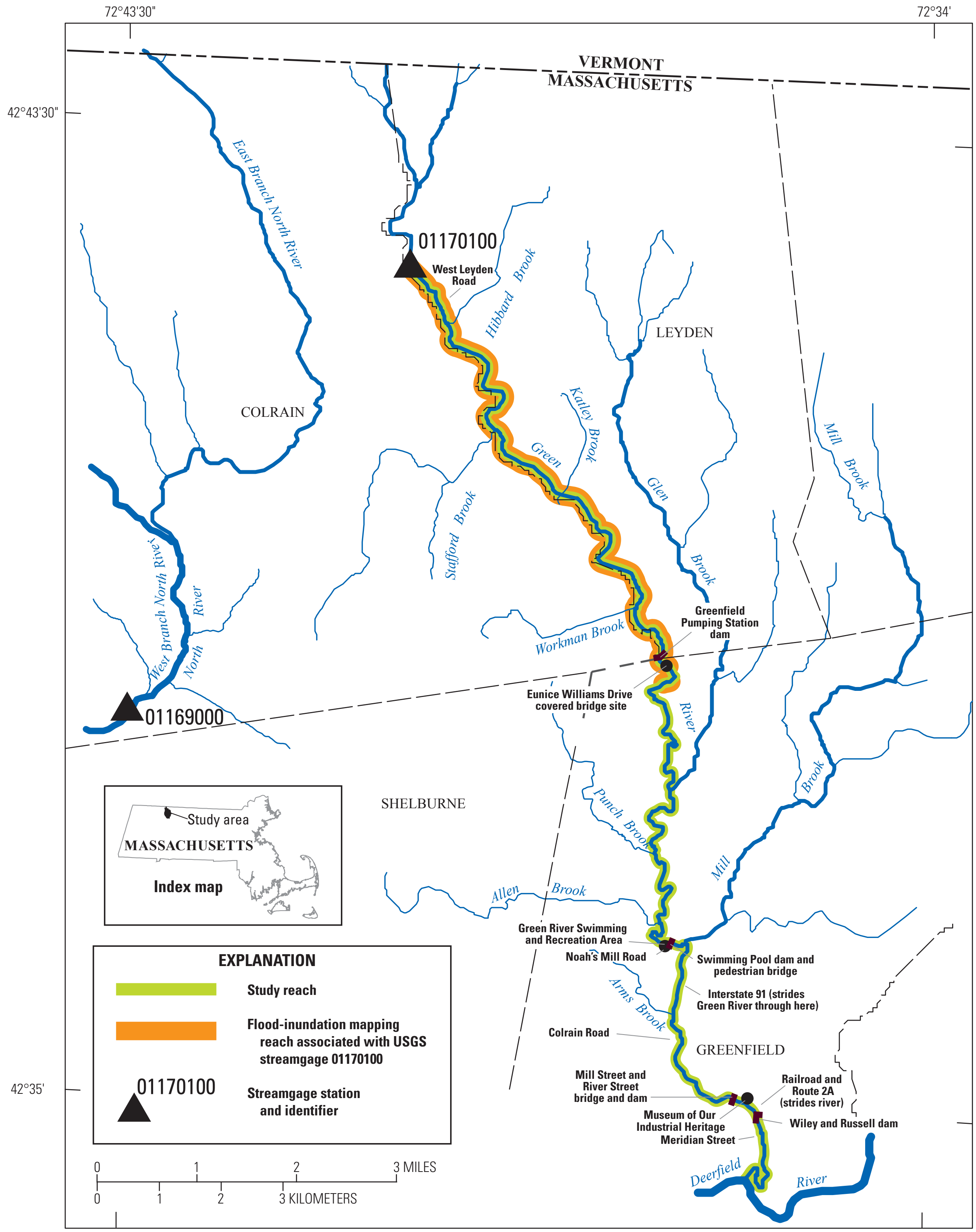
In response to the presidential disaster declaration for Massachusetts, a Federal Emergency Management Agency (FEMA) mission assignment was authorized for the USGS to locate and survey the elevations of high-water marks (HWMs) in the Deerfield and Hoosic River Basins (not shown) of northwestern Massachusetts, including the Green River from the USGS streamgage 01170100 to the confluence with the Deerfield River in Colrain, Leyden, and Greenfield, Mass. An April 2012 interagency agreement between FEMA (Region I, New England) and the USGS authorized the development of a set of flood-inundation maps that would cover a range of stages from near bankfull to the highest recorded stage at the streamgage. Bankfull discharge was estimated to be 2,340 ft^3/s, which is a stage of 7.56 ft using the current (2015) stage-discharge rating curve 34. The flood of August 2011 corresponds to a flood stage (referenced to the streamgage) gage height of 13.97 ft.

Before this study, emergency responders in Colrain, Leyden, and Greenfield relied on several information sources to make decisions on how to best alert the public and mitigate flood damages. One source is the FEMA flood insurance studies for these municipalities (Federal Emergency Management Agency, 1980a, 1980b). There is no FEMA flood insurance study for the town of Leyden. A second source of information is the Green River streamgage from which current (2015) and historical (since 1967) river stage and discharges, including annual peak flows, can be obtained (U.S. Geological Survey, 2014b).

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 a flood-inundation map library that is referenced to the flood stages recorded at the USGS streamgage. 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 will soon be flooded, 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 and water-surface elevations for selected AEP discharges from about the 50- to 0.2-percent AEP discharges for a 14.3-mile (mi) reach of the Green River in Colrain, Leyden, and Greenfield, Mass., from the USGS Green River near Colrain, MA (01170100) streamgage downstream to the confluence with the Deerfield River. This report also describes the flow frequency analyses that were used as hydrologic input to the hydraulic model and the creation of a series of flood-inundation maps for a 4.4-mi modeled section of the upstream part of the 14.3-mi river reach. The maps cover a range in flood stages, referenced to the streamgage, ranging from 7.6 feet (ft; 439.9 ft above the North American Vertical Datum of 1988 [NAVD 88]) to 14.4 ft (446.66 ft above NAVD 88), which cover the range of flood flows from bankfull (about the



Base from Office of Geographic Information (MassGIS), digital data, 1;25,000, 2001
Lambert conformal conic projection. North American Datum 1983 (NAD 83)

Figure 1. Location of Green River study reach in Colrain, Leyden, and Greenfield, Massachusetts, and U.S. Geological Survey streamgages in the region.

50-percent AEP) to the top of the current (2015) USGS rating curve at the streamgage (flood flow higher than the 0.2-percent AEP), and includes the August 28, 2011, (Tropical Storm Irene) maximum recorded water level at the streamgage. The flood inundation maps are 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 Green River is in Franklin County (not shown) in northwestern Massachusetts. The study reach flows south beginning at the Green River streamgage (01170100), at the border between Colrain and Leyden, to the town border of Greenfield, where it flows south through Greenfield to its confluence with the Deerfield River (fig. 1). There are several tributaries to the Green River within the study reach: Hibbard Brook (0.99 square mile [mi^2]), Stafford Brook (2.37 mi^2), Katley Brook (0.59 mi^2), Workman Brook (1.01 mi^2), Glen Brook (7.35 mi^2), Punch Brook (6.37 mi^2), Allen Brook (3.22 mi^2), Mill Brook (10.9 mi^2), Arms Brook (0.96 mi^2), and several unnamed tributaries. The Green River streamgage (01170100) is about 8.8 mi north-northwest of the town center of Greenfield and is approximately 14.3 mi from the downstream end of the reach at the confluence with the Deerfield River and approximately 2.6 mi downstream from the Vermont State line (fig. 1). The streamgage has a drainage area of 41.2 mi^2. The study reach is traversed by 12 bridges and includes 4 low-head dams.

Creation of Flood-Inundation Map Library

The USGS has standardized the procedures for creating flood-inundation maps for flood-prone communities. Tasks specific to development of the flood maps for this study of the Green River are (1) collection of topographic and bathymetric data for selected cross sections and 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 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 a USGS flood-inundation mapping application.

Computation of Water-Surface Profiles

The water-surface profiles used to produce the seven flood-inundation maps in this study 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 with steady-state (gradually varied) or unsteady-state flow computation options.

Hydrology

The study reach includes the Green River streamgage, which has been in operation since October 1967 of water year[1] 1968 (fig. 1; table 1). The Green River streamgage is approximately 0.5 mi upstream from the bridge at West Leyden Road and 2.5 mi northeast of Colrain, Mass. The river stage is measured every 15 minutes, transmitted hourly via satellite, and is available at the USGS National Water Information System (NWIS) Web site (U.S. Geological Survey, 2014b). River stage data from this streamgage are referenced to a local datum but can be converted to water-surface elevations referenced to NAVD 88 by adding 432.26 ft. Continuous records of streamflow at the streamgage are computed from a stage-discharge relation (rating curve) developed through concurrent stage and streamflow

[1]A water year is the 12-month period beginning October 1 and ending September 30 and is designated by the calendar year in which it ends.

Table 1. Information about U.S. Geological Survey Green River near Colrain, MA (01170100) streamgage.

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

Site information	
Station name	Green River near Colrain, MA
Station number	01170100
Drainage area	41.4 mi^2
Latitude (decimal degrees, NAD 83)	42.703417
Longitude (decimal degrees, NAD 83)	-72.670647
Period of peak-flow record, in water years[1]	1968 to present
Maximum stage (gage datum [elevation, above NAVD 88]); date	13.97 (446.24 ft); August 28, 2011[2]
Maximum discharge; date	13,200 ft^3/s; August 28, 2011

[1]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.

[2]The maximum stage of 13.97 ft was based on high-water marks collected at the streamgage.

measurements available since October 1967. The current (2015) rating curve is number 34 (U.S. Geological Survey, 2014b).

Discharges input to the hydraulic model at the streamgage location correspond to flood stages referenced to the Green River streamgage for the 50-, 10-, 1-, and 0.2-percent AEPs (table 2) and flood stages of 10.2, 12.4, and 14.4 ft. The estimated AEP discharges are weighted values calculated by combining the at-site and regional regression estimates with the inverse of the variance of these estimates (U.S. Geological Survey, 2014c). The at-site flood-stage estimates for the Green River streamgage were based on 46 years of record (water years 1968–2013) and were determined by the standard log-Pearson type III method described in Interagency Advisory Committee on Water Data (1982) and a modification of this method called the expected moments algorithm (Cohn and others, 1997, 2001; Griffis and others, 2004). The regional regression estimates (Olson, 2014) use the drainage area (in square miles), the area of a basin covered by wetlands and open water (as a percentage), and the basinwide mean annual precipitation (in inches) to estimate flow statistics. Peak flows at the streamgage were transferred 14.3 mi downstream from the streamgage (the study reach downstream limit) using a drainage-area ratio method that combines regression equation estimates at the new location with the weighted estimates computed at the streamgage site (table 2; Olson, 2014, eqs. 19 and 20).

The 50-, 10-, 1-, and 0.2-percent AEPs correspond to stages of 7.6, 9.1, 11.4, and 14.4 ft, respectively, at the Green River streamgage. Discharges corresponding to the flood stages of 10.2, 12.4, 13.97, and 14.4 ft were also modeled. The streamgage stage of 13.97 ft corresponds to the flood peak for Tropical Storm Irene at the Green River streamgage, while the stages of 10.2 and 12.4 ft were added as intermediate stages between the 10- and 1-percent and 1- and 0.2-percent AEPs. The stage of 14.4 ft at the Green River streamgage corresponds to the top of the current (2015) USGS rating curve number 34.

The 50-, 10-, 1-, and 0.2-percent AEP flows and the flood flows at a stage of 10.2, 12.4, and 14.4 ft for the Green River streamgage were transferred downstream to the confluence of the Green River with the Deerfield River with a drainage-area ratio method using the following equation:

$$Q_u = Q_g \left(\frac{DA_u}{DA_g} \right)^e \qquad (1)$$

where,

Q_u is the streamflow at ungaged location, in cubic feet per second;

Q_g is the streamflow at gaged location, in cubic feet per second;

DA_u is the drainage area at ungaged location, in square miles;

DA_g is the drainage area at gaged location, in square miles; and

e is the exponent of the drainage-area-only regional regression equations, which was interpolated for the flows at the selected stages using the exponents determined by Olson (2014) for selected AEPs (table 3).

Table 2. Peak-discharge estimates for the 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent annual exceedance probabilities for the U.S. Geological Survey Green River near Colrain, MA streamgage (01170100).

[Calculated using the expected moments algorithm (EMA), regional regression equations, and weighted estimate method. ft^3/s, cubic foot per second; log_{10}, logarithm base 10]

Annual exceedance probability, in percent	Peak flow, in ft^3/s	EMA using annual peak flows for water years 1941–2013			Vermont regional regression equation[1]		Weighted estimate[2]	
		Variance, in log_{10} units	Confidence interval: Lower 95 percent	Confidence interval: Upper 95 percent	Peak flow (ft^3/s)	Variance (log_{10} units)	Peak flow (ft^3/s)	Variance (log_{10} units)
50	2,380	0.0010	2,070	2,770	1,660	0.0213	2,340	0.0010
20	3,640	0.0017	3,090	4,540	2,580	0.0226	3,550	0.0016
10	4,650	0.0025	3,840	6,250	3,280	0.0258	4,510	0.0023
4	6,170	0.0042	4,870	9,270	4,330	0.0305	5,910	0.0037
2	7,490	0.0058	5,700	12,300	5,220	0.0339	7,100	0.0050
1	8,970	0.0079	6,590	16,300	6,180	0.0371	8,400	0.0065
0.5	10,600	0.0103	7,520	21,400	7,250	0.0421	9,840	0.0083
0.2	13,200	0.0140	8,860	30,300	8,860	0.0489	12,100	0.0109

[1]The Vermont regional regression equation is from Olson (2014).

[2]Weighted estimate method is described in U.S. Geological Survey (2014c).

Table 3. Exponent of drainage area used to calculate flood flows for annual exceedance probabilities for the Green River in Colrain, Leyden, and Greenfield, Massachusetts.

Annual exceedance probability, in percent	Exponent of drainage area[1]
50	0.869
20	0.855
10	0.847
4	0.838
2	0.833
1	0.827
0.5	0.822
0.2	0.816
Flood peak flow on August 28, 2011 (Tropical Storm Irene)	0.816

[1]Exponent of drainage area is variable *e* used in equation 1 of this report. The exponents of drainage area are from Olson (2014).

For the selected flood stages of 10.2, 12.4, 13.97, and 14.4 ft, the exponent for equation 1 was interpolated from the exponent of the AEP flow for flows lower and higher than the flow at that stage. For the flood stages at 10.2, 12.4, and 14.4 ft, the exponent used in equation 1 was 0.847 and for the flood stage of 13.97, the exponent used in equation 1 was 0.816. Adjustments to the estimated flows were made to account for inflows from tributaries—Hibbard, Strafford, Katley, Glen, Punch, Allen, Mill, Workman, and Arms Brooks and several unnamed tributaries (fig. 1). Inflows from other tributaries were considered inconsequential to the computation of water-surface elevations along the study reach because of the magnitude of flows in the Green River. Drainage adjustments were made for the entire river reach downstream from the Green River streamgage to its confluence with the Deerfield River (table 4).

Topographic and Bathymetric Data

All topographic data used in the model are referenced vertically to 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 collected in March and April 2012 by Northrop Grumman Information Systems, Advanced GEOINT Solutions Operating Unit (National Oceanic and Atmospheric Administration, 2013). 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 101 cross sections and subsequently input into the HEC–RAS model. Because the lidar data do not 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 and hydraulic structure (bridges and dams) during August and October 2012 and July and August 2013. Twenty-two measurements of the elevations at four National Geodetic Survey benchmark (permanent identification numbers MZ0232, MZ0280, MZ0286, and MZ1181) locations in Franklin County, Mass., during August and October 2012 and July and August 2013 differed from their known elevations by 0.019 to 0.224 ft. The median difference of these 22 RTK DGPS measurements from the known elevations of these 4 benchmarks was 0.075 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). Sixteen structures, consisting of 12 bridges (West Leyden Road, Eunice Williams Drive, pedestrian bridge over dam at Green River Swimming and Recreation Area, Nash's Mill Road, bike path bridge, Interstate I–91 South and North, Colrain Street, Route 2A [Mohawk Trail], a railroad bridge, bridge at intersection of Mill Street and River Street, Meridian Street, and pedestrian bridge at end of Petty Plain Road) and four dams (Greenfield Water Pumping Station dam upstream from Eunice Williams Road, dam under pedestrian bridge at Green River Swimming and Recreation Area, dam upstream from bridge at intersection of Mill Street and River Street, and historic Wiley and Russell Dam upstream from Meridian Street) have the potential to affect water-surface elevations during floods along the stream reach. Bridge-geometry and cross-section data were obtained from field surveys by USGS personnel during August and October 2012 and July and August 2013, respectively. Data for the Eunice Williams Drive covered bridge were updated with new, additional elevations based on the rehabilitation of the structure in 2014 (Robert Durfee, Dubois & King, Inc., written commun., 2015).

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 based on field observations and high-resolution aerial photographs. The upstream end of the reach is characterized by boulders and cobbles leading to higher channel *n*-values ranging from 0.04 to 0.055. The middle section of

Table 4. Estimated discharges for the 50-, 10-, 1-, and 0.2-percent annual exceedance probabilities and flood stages of 10.2, 12.4, 13.97, and 14.4 ft as referenced to the U.S. Geological Survey Green River near Colrain, MA (01170100) streamgage and at selected locations on the Green River in Colrain, Leyden, and Greenfield, Massachusetts.

[ft, foot; mi^2, square mile; ft^3/s, cubic foot per second; USGS, U.S. Geological Survey]

Location on Green River in model, in ft upstream from confluence with Deerfield River	Description of location on Green River	Drainage area, in mi^2	Estimated peak discharge, in ft^3/s, for annual exceedance probabilities or stage, as appropriate							Peak flow on August 28, 2011 (Tropical Storm Irene)[2]
			50 percent[1]	10 percent[1]	Stage of 10.2 ft at USGS streamgage 01170100	1 percent[1]	Stage of 12.4 ft at USGS streamgage 01170100	0.2 percent[1]	Stage of 14.4 ft at USGS streamgage 01170100	
75,577	USGS Green River near Colrain, MA (01170100) streamgage	41.2	2,340	4,510	6,290	8,400	10,300	12,100	14,000	13,200
72,713	About 100 ft upstream from West Leyden Road bridge	41.9	2,540	4,885	6,813	9,081	11,156	13,067	15,163	13,772
62,263	Downstream from Stafford Brook tributary	47.7	2,783	5,341	7,449	9,908	12,197	14,241	16,579	14,441
48,213	At confluence with Workman Brook tributary	50.5	2,914	5,586	7,791	10,351	12,757	14,870	17,340	14,789
31,967	Downstream from Glen Brook and upstream from Hinsdale and Punch Brook tributaries	60.5	3,287	6,280	8,759	11,606	14,343	16,647	19,495	15,739
26,028	Upstream from Allen Brook tributary	67.3	3,585	6,836	9,534	12,608	15,612	18,064	21,221	16,464
21,746	Upstream from dam at Green River recreation area	71.0	3,759	7,158	9,983	13,188	16,348	18,883	22,220	16,872
19,219	Upstream from Mill Brook tributary and Nash's Mills Road bridge	71.1	4,341	8,238	11,489	15,126	18,813	21,619	25,571	18,179
12,213	Upstream from Smead Brook tributary	83.9	4,454	8,445	11,778	15,498	19,287	22,143	26,215	18,421
11,270	Upstream from State Route 2 bridge	86.9	4,454	8,445	11,778	15,498	19,287	22,143	26,215	18,421
9,206	Downstream from railroad bridge and upstream from River Street and Mill Street bridge	88.4	4,552	8,627	12,032	15,824	19,702	22,602	26,780	18,631
8,054	Upstream from River Street and Mill Street bridge	88.6	4,586	8,690	12,120	15,937	19,847	22,762	26,976	18,703
6,104	Downstream from Wiley and Russell dam and upstream from Meridian Street bridge	88.9	4,586	8,690	12,120	15,937	19,847	22,762	26,976	18,703
20	Upstream from confluence with Deerfield River	89.4	4,586	8,690	12,120	15,937	19,847	22,762	26,976	18,703

[1]The 50-, 10-, 1-, and 0.2-percent annual exceedance probabilities associated stages at USGS Green River near Colrain, MA streamgage (01170100) are 7.6, 9.1, 11.4, and 13.4 ft, respectively.

[2]The peak flow on August 28, 2011 (Tropical Storm Irene), had a stage of 13.97 ft.

the reach had *n*-values from 0.02 to 0.04, and the downstream section had *n*-values from 0.02 to 0.035. The upstream and middle sections of the reach in Colrain and Leyden are fairly rural, and the overbanks are mostly forested riparian with a few farm fields, thus *n*-values for the overbank areas generally range from 0.06 to 0.10. Although the downstream section of the reach is somewhat developed in Greenfield, the overbanks are mostly in the forested riparian corridor, and thus *n*-values generally vary from 0.05 to 0.10, depending on the openness of the section. Slopes vary from approximately 0.006 in the upper one-half of the reach to approximately 0.002 in the lower one-half of the reach. 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. The final *n*-values ranged from 0.02 to 0.055 for the main channel and from 0.05 to 0.10 for the overbank areas modeled in this analysis.

The HEC–RAS analysis was done 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 0.001. The HEC–RAS model was calibrated to the current [2015] stage-discharge relation at the Green River streamgage and to documented HWMs from Tropical Storm Irene in August 2011 (Bent and others, 2013). Model calibration to Tropical Storm Irene HWMs was accomplished by adjusting Manning's roughness coefficients (*n*-values) until the results of the hydraulic computations closely agreed with the observed water-surface elevations for given flows downstream from the Green River streamgage during Tropical Storm Irene.

Differences between surveyed and modeled elevations of 26 HWMs in the study reach for the August 28, 2011, flood (Tropical Storm Irene) were an (absolute) average of 0.48 ft and from 0.00 to 0.49 ft for 15 of the 26 HWMs, 0.50 to 0.99 ft for 8 HWMs, and 1.00 to 1.60 for 3 HWMs (table 5). Sixteen of the 26 HWMs (table 5) have negative differences between the surveyed and modeled water-surface elevations (surveyed elevation is lower than the modeled elevation), but

Table 5. Calibration of hydraulic model to water-surface elevations at selected locations along the Green River in Colrain, Leyden, and Greenfield, Massachusetts, for the Tropical Storm Irene (August 28, 2011) flood.

[HWM, high-water mark; ID, identification number; NAVD 88, North American Vertical Datum of 1988]

River station, in feet[1]	HWM ID[2]	HWM rating[2]	Water-surface elevation, in feet above NAVD 88		Difference in elevation, in feet
			Surveyed HWM[2]	Model simulated	
2,639	HWM–MA–GREEN–063	Excellent	141.75	141.92	-0.17
4,421	HWM–MA–GREEN–066	Good	144.05	143.01	1.04
4,227	HWM–MA–GREEN–067	Excellent	142.28	141.70	0.58
5,676	HWM–MA–GREEN–071	Fair	143.75	143.13	0.62
7,630	HWM–MA–GREEN–073	Excellent	148.62	150.15	-1.53
8,054	HWM–MA–GREEN–072	Good	155.33	155.07	0.26
10,326	HWM–MA–GREEN–076	Fair	159.51	159.32	0.19
10,666	HWM–MA–GREEN–075	Fair	159.96	160.61	-0.65
12,745	HWM–MA–GREEN–079	Excellent	164.43	163.15	1.28
13,038	HWM–MA–GREEN–078	Excellent	164.13	163.72	0.41
13,157	HWM–MA–GREEN–077	Good	164.31	164.44	-0.13
17,563	HWM–MA–GREEN–082	Poor	168.16	168.15	0.01
17,859	HWM–MA–GREEN–081	Excellent	170.49	170.98	-0.49
18,061	HWM–MA–GREEN–080	Good	171.05	171.38	-0.33
19,279	HWM–MA–GREEN–085	Fair	172.37	172.64	-0.27
19,778	HWM–MA–GREEN–085A	Fair	172.11	172.71	-0.60
20,029	HWM–MA–GREEN–084	Excellent	172.51	172.72	-0.21
43,785	HWM–MA–GREEN–089	Excellent	238.59	238.39	0.20
44,354	HWM–MA–GREEN–088	Good	252.22	252.63	-0.41
72,513	HWM–MA–GREEN–098	Good	424.12	424.77	-0.65
72,584	HWM–MA–GREEN–096	Good	424.26	424.77	-0.51
72,625	HWM–MA–GREEN–092	Good	426.82	427.51	-0.69
74,769	HWM–MA–GREEN–106	Fair	442.79	443.00	-0.21
75,112	HWM–MA–GREEN–102	Good	445.27	444.80	0.47
75,392	HWM–MA–GREEN–101	Good	447.51	447.54	-0.03
75,577	HWM–MA–GREEN–100	Fair	448.35	448.86	-0.51

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

[2]From Bent and others (2013).

field crews sometimes inadvertently collect a HWM that is lower than the final water-surface elevation of a flood because marks can remain from the falling limb of the hydrograph. Overall, the results demonstrate that the model is capable of simulating accurate water levels over a wide range of flows in the basin.

Development of Water-Surface Profiles

The calibrated hydraulic model was used to generate water-surface profiles for a total of seven flood stages between 7.6 ft and 14.4 ft, as referenced to the local datum of the Green River streamgage (01170100; table 6). The 7.6- and 14.4-ft stages correspond to NAVD 88 elevations of 439.9 ft and 446.7 ft, respectively. The mapped stages from 7.6 to 14.4 (table 6) were selected to match the flood stage from about bankfull (about the 50-percent AEP flood also called the 2-year recurrence interval flood; Bent and Waite, 2013) to an AEP of less than 0.2 percent also called the 500-year recurrence interval flood (maximum stage in the current [2015] Green River streamgage rating curve 34) and exceeds the maximum recorded water level of 13.97 ft at the streamgage (Tropical Storm Irene).

The seven mapped stages (table 6) only include the 50-, 10-, 1-, and 0.2-percent AEPs because the 20-, 4-, 2-, and 0.5-percent AEPs were within 1-ft stage of the higher or lower AEPs mapped. Additionally, where there was at least a 2-ft difference in stage between the mapped AEPs, incremental stages of 10.2 ft and 12.4 ft were added, and 14.4 ft was added because it was the maximum stage in the rating and greater than the Tropical Storm Irene flood stage of 13.97 ft. Rating curve 34 includes stages from discharges that were transferred downstream from the Green River streamgage using the methods discussed in the “Hydrology” section of this report. The model-simulated water-surface elevations for 7.6-, 9.1-, 10.2-, 11.4-, 12.4-, 13.4-, 13.97-, and 14.4-ft stages at the streamgage are tabulated in appendix 1.

Table 6. Stage, elevation, discharge, and annual exceedance probabilities at the U.S. Geological Survey Green River near Colrain, MA (01170100) streamgage for profiles mapped on the Green River in Colrain, Leyden, and Greenfield, Massachusetts.

[ft, foot; NAVD 88, North American Vertical Datum of 1988; ft^3/s, cubic foot per second; NA, not applicable]

Grid identification[1]	Stage, in ft	Elevation, in ft above NAVD 88	Discharge, in ft^3/s	Annual exceedance probability, in percent
GreenMA_01	7.6	439.9	2,340	50
GreenMA_02	9.1	441.4	4,510	10
GreenMA_03	10.2	442.5	6,290	NA
GreenMA_04	11.4	443.7	8,400	1
GreenMA_05	12.4	444.7	10,300	NA
GreenMA_06	13.4	445.7	12,100	0.2
GreenMA_07[2]	14.4	446.7	14,000	NA

[1]Grids refer to flood inundation maps on the U.S. Geological Survey Flood Inundation Mapping Program Web site (http://water.usgs.gov/osw/flood_inundation).

[2]The GreenMA_07 map approximately depicts the Tropical Storm Irene flood of August 28, 2011, at this streamgage, which had a maximum recorded stage of 13.97 ft.

Flood-Inundation Maps

Flood-inundation maps were created in a GIS for the seven water-surface profiles by combining the profiles and DEM data. The maps depict the flood-plain boundaries of the 7.6- to 14.4-ft stages at the Green River streamgage (table 4), which encompasses the stages associated with the 50-, 10-, 1-, and 0.2-percent AEP flood discharges and the incremental stages of 10.2, 12.4, and 14.4 ft.

The DEM data were derived from the lidar data described in the “Topographic and Bathymetric Data” section of this report and have an estimated vertical accuracy of 1 ft plus or minus (±) 1 ft. Estimated flood-inundation boundaries for each simulated profile were developed with HEC–GeoRAS computer program (U.S. Army Corps of Engineers, Hydrologic Engineering Center, 2009), which allows the preparation of geometric data for import into HEC–RAS computer program (U.S. Army Corps of Engineers, Hydrologic Engineering Center, 2010) 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 ArcGIS (Esri Inc., 2014) to ensure a hydraulically reasonable transition of the flood boundaries between modeled cross sections.

The flood-inundation areas are overlaid on high-resolution, geospatial-referenced aerial photographs of the study area (fig. 2). 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 noninundated 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 the earth surface in the vicinity of the building is 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 of this report.

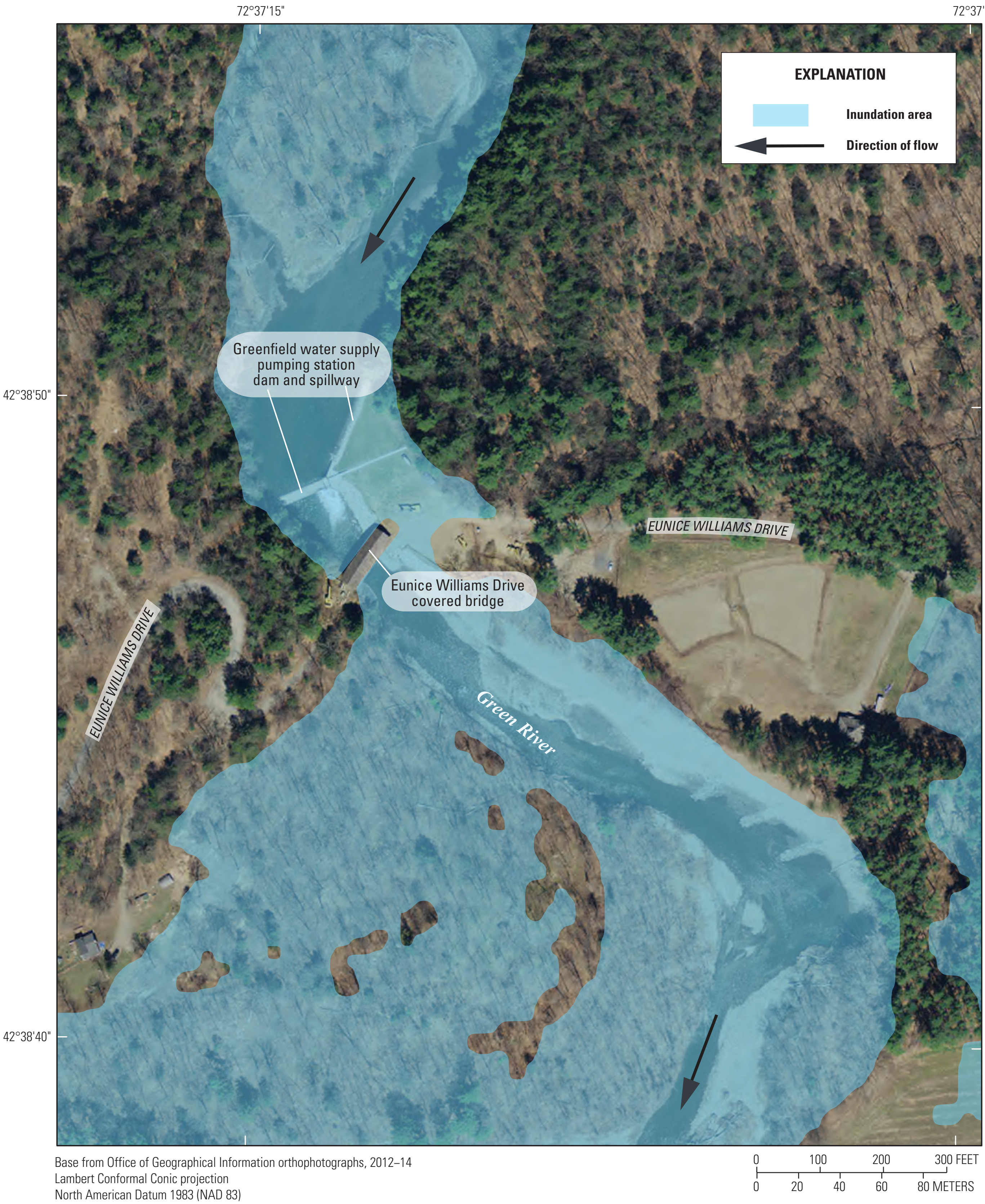


Figure 2. Flood-inundation for a downstream region on the Green River study reach that corresponds to a stage of 14.4 feet at the U.S. Geological Survey Green River near Colrain, MA (01170100) streamgage (not shown on map).

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 reaches 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. 2). The flood-inundation maps are displayed in sufficient detail so that preparations for flooding and decisions for emergency response can be done efficiently. The Flood Inundation Mapper links to the USGS NWIS Web page for the Green River streamgage (U.S. Geological Survey, 2014b), which presents the real-time stage and streamflow to which the inundation maps are referenced. Shapefiles depicting flood-plain boundaries for the 1- and 0.2-percent AEP floods are available through Web links presented in appendix 2.

Disclaimer for Flood-Inundation Maps

Flood-inundation maps should not be used for navigation, regulatory, permitting, or other legal purposes. The USGS 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 water surfaces, and the mapping. The flood boundaries shown were estimated on the basis of flood stages and streamflows at the Green River streamgage. There are errors associated with the stage-discharge rating curves used to estimate flow at the streamgages because 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 2 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 as of the surveying in August and October 2012 and July and August 2013. 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. The HEC–RAS model is more accurate when calibrated to flows from streamgages and to HWMs collected after flooding events. The HWMs collected in the field are from actual events and are given a rating from poor (±0.2 ft) to excellent (±0.05 ft) at the time they are collected (table 5). The HWMs collected in the field are from actual events and are given a rating from poor (±0.2 ft) to excellent (±0.05 ft) at the time they are collected (table 5). Thus, the models are as good as the data to which they are calibrated.

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. Thus, the mapping of the flood boundaries and the depths of the inundated areas on the maps have some uncertainty.

Summary

The U.S. Geological Survey (USGS) developed flood elevations in cooperation with the Federal Emergency Management Agency for the 14.3-mile reach of the Green River in Colrain, Leyden, and Greenfield, Massachusetts, from the USGS Green River near Colrain, MA (01170100) streamgage to its confluence with the Deerfield River. A series of seven flood-inundation maps were developed for the upper 4.4 miles of the river reach downstream from the Green River streamgage. 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 relation (rating curve 34) at the USGS Green River near Colrain, MA (01170100) streamgage and to the peak water-surface elevations (high-water marks) along the 14.3-mile reach from the Tropical Storm Irene flood on August 28, 2011 (stage 13.97 feet).

The hydraulic model was used to compute seven water-surface profiles for flood stages referenced to the streamgage datum and ranging from 7.6 feet (439.9 feet above the North American Vertical Datum of 1988), which is near bankfull, to 14.4 feet (446.7 feet above the North American Vertical Datum of 1988). Modeled water-surface profiles correspond to the 50-, 10-, 1-, and 0.2-percent annual exceedance probability flood, making them consistent with Federal Emergency Management Agency flood recovery maps for the 1- and 0.2-percent annual exceedance probabilities. Additional stages were mapped at 10.2 and 12.4 feet where the gap between the stages corresponding to the annual exceedance probability floods exceeded 2 ft. The modeled 14.4-foot stage is the top of the current (2015) rating curve for the streamgage and is higher than the 0.2-percent annual exceedance probability flood and the flood on August 28, 2011 (Tropical Storm Irene).

Water-surface profiles were combined with a geographic information system digital elevation model derived from light detection and ranging 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, georeferenced 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 cursor to click within the shaded areas. These maps, in conjunction with the real-time stage data from the Green River near Colrain streamgage, will help guide the general public in taking individual safety precautions and 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 1–2

Appendix 1. Simulated Water-Surface Elevations at Modeled Cross Sections Along the Green River Study Reach in Colrain, Leyden, and Greenfield, Massachusetts.

Appendix 2. Shapefiles of Flood Inundation Areas for the 1- and 0.2-Percent Annual Exceedance Probability Flows Along the Green River Study Reach in Colrain, Leyden, and Greenfield, Massachusetts.

[Shapefiles can be accessed at http://dx.doi.org/sir20165107]

Appendix 1. Simulated Water-Surface Elevations at Modeled Cross Sections Along the Green River Study Reach in Colrain, Leyden, and Greenfield, Massachusetts.

Table 1–1. Simulated water-surface elevations corresponding to the 50-, 10-, 1-, and 0.2-percent annual exceedance probabilities (AEPs; 7.6, 9.1, 11.4, and 13.4 ft, respectively); flood stages of 10.2, 12.4, 13.97, and 14.4 ft; and the 1-percent AEP floodway as referenced to the U.S. Geological Survey Green River near Colrain, MA streamgage station (01170100) along the Green River in Colrain, Leyden, and Greenfield, Massachusetts.

[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; AEP, annual exceedance probability]

Cross-section ID, in ft[1]	Water-surface elevation, in ft above NAVD 88								1% AEP floodway, in ft
	Annual exceedance probability and stage				Flood stage				
	50%, 7.6 ft	10%, 9.1 ft	1%, 11.4 ft	0.2%, 13.4 ft	10.2 ft	12.4 ft	13.97 ft[2]	14.4 ft	
75,577	442.04	444.04	446.69	448.37	445.36	447.65	448.86	449.16	446.78
75,392	439.88	442.05	444.74	446.87	443.36	445.85	447.54	447.99	444.94
75,112	437.64	439.96	442.63	444.30	441.33	443.55	444.72	445.00	442.83
74,769	436.13	438.26	440.85	442.55	439.60	441.77	443.00	443.30	440.95
74,047	428.59	429.71	431.31	432.60	430.49	431.99	432.96	433.23	431.31
72,713	418.74	421.28	424.99	428.29	423.00	426.75	428.87	429.80	424.99
72,625	418.15	420.40	423.81	426.95	421.96	425.48	427.51	427.99	423.81
72,584	417.96	419.87	422.42	424.49	421.04	423.63	424.77	423.18	422.42
72,513	415.70	417.36	419.40	420.95	418.35	420.25	421.19	421.66	419.40
70,799	401.37	402.99	405.14	406.78	404.06	406.02	407.03	407.55	405.14
69,054	390.61	392.49	395.00	396.85	393.75	396.01	397.17	397.70	395.00
67,374	380.14	381.74	383.78	385.19	382.76	384.56	385.38	385.86	383.78
65,005	361.70	363.40	365.94	367.88	364.62	367.04	368.21	368.69	365.94
63,811	354.11	356.31	359.25	361.49	357.78	360.55	361.66	362.41	359.25
62,283	342.00	343.78	346.24	348.11	344.97	347.25	348.19	349.04	346.24
59,717	327.64	329.86	332.64	334.49	331.41	333.68	334.56	335.28	332.64
58,840	325.55	327.22	329.90	331.69	328.76	330.90	331.77	332.52	329.90
56,524	311.36	313.59	316.20	318.21	314.92	317.26	318.29	319.12	316.20
53,984	295.48	296.88	299.00	300.45	297.94	299.85	300.52	301.20	299.00
52,387	284.84	287.23	289.92	291.97	288.62	290.96	292.05	292.92	289.92
50,495	275.18	276.47	278.07	279.05	277.24	278.76	279.10	279.56	278.07
48,213	262.95	265.17	267.45	268.80	266.41	268.28	268.77	269.49	267.45
46,409	253.17	254.01	255.62	257.17	254.69	256.48	257.15	258.03	255.68
45,252	245.78	247.58	250.84	252.73	249.30	251.89	252.70	253.71	250.84
44,258	245.73	247.91	250.89	252.66	249.42	251.87	252.63	253.59	250.89
44,160	245.71	247.86	250.78	252.48	249.35	251.73	252.46	253.38	250.78
44,129	236.72	239.44	242.80	246.56	240.88	244.49	246.50	249.77	242.80
44,074	236.46	238.97	242.21	246.14	240.24	243.92	246.08	249.54	242.21
44,027	236.19	238.52	240.83	245.17	239.26	242.34	245.11	249.26	240.83
43,991	235.99	238.38	238.80	240.85	237.49	239.88	240.81	242.10	238.80
43,899	234.33	235.11	236.60	238.43	235.95	237.54	238.39	239.25	236.70
42,537	225.59	227.92	229.70	231.16	228.70	230.54	231.14	231.27	229.95

Table 1–1. Simulated water-surface elevations corresponding to the 50-, 10-, 1-, and 0.2-percent annual exceedance probabilities (AEPs; 7.6, 9.1, 11.4, and 13.4 ft, respectively); flood stages of 10.2, 12.4, 13.97, and 14.4 ft; and the 1-percent AEP floodway as referenced to the U.S. Geological Survey Green River near Colrain, MA streamgage station (01170100) along the Green River in Colrain, Leyden, and Greenfield, Massachusetts.—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; AEP, annual exceedance probability]

Cross-section ID, in ft[1]	Water-surface elevation, in ft above NAVD 88								1% AEP floodway, in ft
	Annual exceedance probability and stage				Flood stage				
	50%, 7.6 ft	10%, 9.1 ft	1%, 11.4 ft	0.2%, 13.4 ft	10.2 ft	12.4 ft	13.97 ft[2]	14.4 ft	
40,677	215.88	216.35	218.28	219.37	217.57	218.84	219.34	220.22	218.63
38,672	207.04	209.21	209.66	210.66	209.01	210.22	210.65	211.15	210.56
36,505	198.11	197.98	198.67	199.26	198.26	198.99	199.25	199.54	198.92
31,967	181.69	184.95	186.17	187.71	185.23	186.99	187.48	188.41	187.12
29,291	177.93	180.31	182.54	183.84	181.35	183.25	183.77	184.09	183.50
26,028	170.71	172.52	173.23	175.69	172.55	174.49	174.53	178.19	174.08
23,678	164.97	167.61	171.42	174.84	169.26	173.35	173.07	177.69	172.05
21,746	163.46	167.04	171.11	174.62	168.84	173.10	172.78	177.54	171.72
19,805	162.92	166.90	171.05	174.58	168.75	173.05	172.72	177.51	171.65
19,778	162.92	166.90	171.05	174.58	168.75	173.05	172.72	177.51	171.65
19,750	162.91	166.89	171.04	174.57	168.74	173.04	172.71	177.50	171.64
19,724	162.90	166.89	171.04	174.57	168.74	173.04	172.71	177.50	171.64
19,219	162.53	166.76	170.97	174.51	168.65	172.98	172.64	177.45	171.56
19,133	162.42	166.69	170.95	174.50	168.62	172.96	172.62	177.45	171.54
19,095	162.30	166.58	170.90	174.46	168.55	172.92	172.59	177.43	171.49
19,057	162.08	166.58	170.91	174.47	168.56	172.93	172.59	177.43	171.49
18,649	161.66	166.30	170.81	174.38	168.43	172.84	172.50	177.36	171.33
18,571	161.61	166.17	170.75	174.32	168.38	172.77	172.44	177.31	171.18
18,061	161.33	165.56	169.76	173.32	167.54	171.72	171.38	176.53	169.84
17,969	161.33	165.62	169.83	173.31	167.61	171.77	171.45	176.20	170.05
17,902	161.16	165.35	169.48	172.91	167.29	171.39	171.06	175.42	169.69
17,882	161.15	165.32	169.47	172.91	167.28	171.39	171.06	175.50	169.56
17,859	161.14	165.32	169.44	172.87	167.26	171.34	171.02	175.34	169.58
17,794	160.42	164.54	168.61	171.98	166.45	170.48	170.17	173.65	169.55
17,725	159.98	163.66	166.96	169.86	165.26	168.46	168.20	171.27	167.68
17,239	159.69	163.30	166.59	169.55	164.87	168.10	167.84	170.97	167.20
16,207	159.02	162.21	164.81	167.38	163.47	165.90	165.70	168.49	165.19
15,202	158.37	161.52	164.16	167.03	162.82	165.29	165.07	168.24	164.45
13,895	157.09	161.07	163.84	166.82	162.49	164.98	164.76	168.04	164.06
13,158	156.15	160.80	163.54	166.59	162.21	164.66	164.44	167.80	163.73
13,079	155.86	160.23	162.87	166.12	161.57	163.95	163.71	167.32	163.14
13,038	155.34	158.70	161.96	165.93	160.19	163.50	163.11	167.12	162.32
12,990	155.42	158.76	162.03	165.95	160.31	163.54	163.15	167.13	162.18
12,213	154.63	157.94	161.23	165.44	159.45	162.69	162.36	166.57	161.43
11,270	152.92	156.45	160.39	165.09	158.35	161.98	161.62	166.21	160.39
10,666	152.20	155.85	159.50	164.38	157.56	160.98	160.64	165.37	159.55

Table 1–1. Simulated water-surface elevations corresponding to the 50-, 10-, 1-, and 0.2-percent annual exceedance probabilities (AEPs; 7.6, 9.1, 11.4, and 13.4 ft, respectively); flood stages of 10.2, 12.4, 13.97, and 14.4 ft; and the 1-percent AEP floodway as referenced to the U.S. Geological Survey Green River near Colrain, MA streamgage station (01170100) along the Green River in Colrain, Leyden, and Greenfield, Massachusetts.—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; AEP, annual exceedance probability]

Cross-section ID, in ft[1]	Water-surface elevation, in ft above NAVD 88								1% AEP floodway, in ft
	Annual exceedance probability and stage				Flood stage				
	50%, 7.6 ft	10%, 9.1 ft	1%, 11.4 ft	0.2%, 13.4 ft	10.2 ft	12.4 ft	13.97 ft[2]	14.4 ft	
10,552	152.08	155.60	158.89	163.66	157.14	160.12	159.84	164.42	158.94
10,477	151.90	155.37	158.44	160.23	156.80	159.50	159.26	161.88	158.50
10,438	151.46	154.92	157.90	159.90	156.21	159.02	158.76	161.87	157.99
10,326	151.69	155.20	158.39	160.54	156.62	159.61	159.32	162.45	158.46
10,267	150.92	154.16	157.30	159.57	155.09	158.54	158.23	161.86	157.44
10,223	150.42	153.20	156.05	159.08	154.44	157.76	157.25	161.55	156.79
10,138	150.52	153.42	156.37	159.30	154.79	158.02	157.55	161.70	156.97
9,206	149.67	152.21	156.15	159.35	154.26	157.98	157.47	161.84	156.16
8,054	149.09	151.02	153.88	156.48	152.44	155.33	154.93	159.01	153.88
7,976	148.96	150.74	153.36	155.89	152.04	154.74	154.37	158.67	153.36
7,911	149.07	151.01	153.79	156.24	152.40	155.16	154.79	158.82	153.79
7,890	142.58	145.74	149.52	153.67	147.59	151.77	151.25	157.12	149.52
7,807	141.94	144.98	148.44	152.83	146.66	150.78	150.28	156.53	148.44
7,026	140.69	143.26	147.54	152.63	145.22	150.34	149.80	156.54	147.54
6,215	139.35	141.03	145.70	151.83	142.45	149.26	148.69	156.03	145.70
6,120	139.54	141.42	146.05	151.97	142.96	149.47	148.90	156.11	146.05
6,104	134.84	139.24	145.82	151.81	142.42	149.29	148.74	156.01	145.83
6,006	134.29	138.41	144.87	151.07	141.47	148.39	147.88	155.52	144.87
5,950	134.06	138.23	144.62	150.85	141.28	148.11	147.62	155.39	144.62
5,908	133.23	137.17	142.66	146.58	139.92	145.13	145.04	149.07	142.66
5,864	131.23	134.65	138.58	143.26	136.70	142.47	143.13	144.69	139.56
5,155	128.58	132.80	137.59	143.39	135.25	142.48	143.20	145.06	138.20
4,389	127.40	131.96	136.76	143.10	134.40	142.17	143.00	144.90	137.71
4,345	127.17	131.16	134.77	140.15	133.16	140.01	141.35	140.97	135.59
4,330	127.09	131.00	134.44	135.15	132.96	134.94	141.20	140.32	135.20
4,252	126.92	131.00	134.66	135.74	133.04	135.34	141.68	141.54	135.52
3,527	126.00	130.04	133.57	135.50	132.07	134.84	141.93	142.11	134.49
2,925	124.35	127.81	131.96	133.31	130.21	132.55	141.93	142.13	132.03
2,276	123.49	127.27	132.00	133.29	129.79	132.62	141.90	142.05	132.17
1,039	117.23	120.36	124.64	129.56	122.51	129.00	141.83	141.91	124.64
20	116.23	118.88	122.56	125.16	120.74	124.15	141.75	141.75	122.56

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

[2]Flood stage of Tropical Storm Irene, August 28, 2011.

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