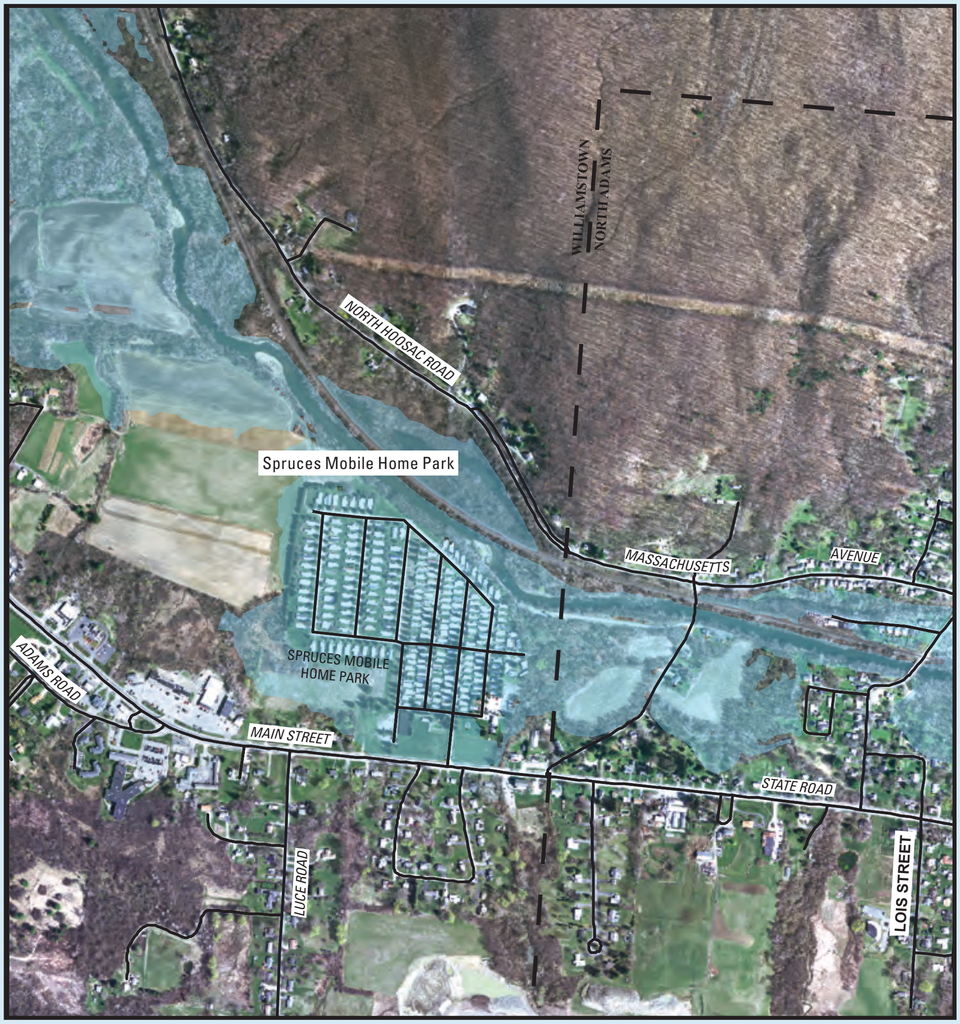
Prepared in cooperation with the Federal Emergency Management Agency

Flood-Inundation Maps for the Hoosic River, North Adams and Williamstown, Massachusetts, From the Confluence With the North Branch Hoosic River to the Vermont State Line



Scientific Investigations Report 2014–5236

U.S. Department of the Interior
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Cover. Flood-inundation map for a region on the Hoosic River near Williamstown, Massachusetts, corresponding to a stage of 15.2 feet (approximately the 0.5-percent annual exceedance probability flood) at the U.S. Geological Survey streamgage station 01332500.

Flood-Inundation Maps for the Hoosic River, North Adams and Williamstown, Massachusetts, From the Confluence With the North Branch Hoosic River to the Vermont State Line

By Pamela J. Lombard and Gardner C. Bent

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U.S. Geological Survey, Reston, Virginia: 2015

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Suggested citation:
Lombard, P.J., and Bent, G.C., 2015, Flood-inundation maps for the Hoosic River, North Adams and Williamstown, Massachusetts, from the confluence with the North Branch Hoosic River to the Vermont state line: U.S. Geological Survey Scientific Investigations Report 2014–5236, 16 p., appendixes, http://dx.doi.org/10.3133/sir20145236.

ISSN 2328-0328 (online)

Acknowledgments

The authors wish to thank the Massachusetts Department of Conservation and Recreation, Office of Water Resources for funding the operation and maintenance of the U.S. Geological Survey (USGS) streamgage at Hoosic River near Williamstown, Massachusetts (01332500), used for this study. Special thanks are given to the National Weather Service Advanced Hydrologic Prediction Service for their forecast of flood stages at the Hoosic River near Williamstown streamgage during times of high water and for their continued support of the USGS Flood-Inundation Mapping Program.

The authors also thank the following USGS field personnel for surveying hydraulic structures and cross sections on the Hoosic River during September and October 2012 and September 2013: Roy Apostle, Dennis Claffey, Adam Hudziec, Andrew Massey, Lance Ostiguy, William Podolski, and Marc Zimmerman

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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)

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 vertical datum.

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
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
NWS	National Weather Service
RTK	real-time kinematic
USGS	U.S. Geological Survey
WIE	Weighted Independent Estimator program

Flood-Inundation Maps for the Hoosic River, North Adams and Williamstown, Massachusetts, From the Confluence With the North Branch Hoosic River to the Vermont State Line

By Pamela J. Lombard and Gardner C. Bent

Abstract

A series of eight digital flood-inundation maps were developed for an 8-mile reach of the Hoosic River in North Adams and Williamstown, Massachusetts, by the U.S. Geological Survey (USGS) in cooperation with the Federal Emergency Management Agency and are available at the USGS flood inundation mapping website at http://water.usgs.gov/osw/flood_inundation. The coverage of the maps extends from the confluence with the North Branch Hoosic River to the Vermont State line. Peak flows with 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 the current (2014) stage-discharge relation at the USGS streamgage Hoosic River near Williamstown, Massachusetts (01332500), and from documented high-water marks from the tropical storm Irene flood, which had approximately a 1-percent annual exceedance probability.

The hydraulic model was used to compute water-surface profiles for flood stages referenced to the streamgage and ranging from 9 feet (ft; 624.45 ft North American Vertical Datum of 1988 [NAVD 1988]), which is near bankfull, to 16.1 ft (631.59 ft NAVD 1988), which exceeds the maximum recorded water level at the streamgage and the National Weather Service major flood stage of 13.0 ft. The mapped stages, from 10.9 to 16.1 ft, were selected to match the stages of flows with annual exceedance probabilities between 20 and 0.2 percent, and thus do not fall at exact 1-ft increments. 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 current (near real-time) stage from USGS streamgage Hoosic River near Williamstown, and forecasted flood stages from the National Weather Service Advanced Hydrologic Prediction Service will provide emergency management personnel and residents with information that is critical for flood response activities such as evacuations and road closures, and post-flood 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-I 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 Hoosic River Basin that ranged from 10- to greater than 1-percent annual exceedance probability (AEP) floods. The peak flow of 14,900 cubic feet per second (ft^3/s) at the Hoosic River near Williamstown streamgage (01332500; fig. 1) is roughly equivalent to the 1-percent AEP flood of 14,500 ft^3/s of the streamgage (Olson and Bent, 2013). The peak discharge at the discontinued North Branch Hoosic River at North Adams streamgage (01332000) was estimated, using indirect flow estimation techniques (Horton, 1907; Hulsing, 1967), to be 13,200 ft^3/s, which is between a 1- and 0.5-percent AEP flood; the peak discharge at Hoosic River at Adams streamgage (01331500) was 2,690 ft^3/s, which is between a 10- and 4-percent AEP flood; and the peak discharge at Green River at Williamstown streamgage (01333000) was 4,140 ft^3/s, which is slightly less than a 2-percent AEP flood.

Damages in the Hoosic River Basin were primarily located on the North Branch Hoosic River and downstream from the USGS streamgage, Hoosic River near Williamstown, Massachusetts (01332500; hereafter referred to as the “Hoosic River streamgage”). The Spruces Mobile Home Park (fig. 2), located 1 mile (mi) downstream from the streamgage, was severely affected by the flooding; two-thirds of the 226 mobile homes were damaged or destroyed (Andy McKeever, iBerkshire, written commun., 2011; Tammy Daniels, iBerkshire, written commun., 2013). The town of Williamstown was awarded a $6.13 million Federal Emergency Management Agency (FEMA) hazard mitigation grant to relocate the current (2014) residents of the Spruces Mobile Home Park, and the town selectmen signed a notice of discontinuance in February 2014 stating that the mobile home park will close February 29, 2016 (Edward Damon, Berkshire Eagle, written commun., 2013). The construction of concrete channels and walls and earthen levees along portions of the Hoosic River and North Branch Hoosic River between 1959 and 1961 by the U.S. Army Corps of Engineers (USACE) was in response to major floods that affected Adams and North Adams, Massachusetts (fig. 1) in 1927, 1936, and 1938. The flood control structures were built to protect Adams and North Adams from floods with up to a 0.2-percent annual exceedance probability (500-year floods) at the time of the analyses (Federal Emergency Management Agency, 1981).

In response to the presidential disaster declaration for Massachusetts, a FEMA mission assignment was authorized for the USGS to locate and survey the elevations of high-water marks (HWMs) in the Hoosic River Basin from the confluence with the North Branch Hoosic River to the Vermont State line, in North Adams and Williamstown, Massachusetts. 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 bankfull, which is roughly the minor flood stage as defined by the National Weather Service (NWS) Advanced Hydrologic Prediction Service (AHPS), to the highest recorded stage at the streamgage (approximately 3 feet [ft] higher than the NWS AHPS major flood stage). The mapped flood stages from 9 to 16.1 ft were selected to match flows with AEPs between 20 and 0.2 percent to meet FEMA’s criteria for being flood recovery maps, but for this reason do not fall at exact 1-ft increments. The flood of August 2011 corresponds to a flood with an AEP of 1 percent; therefore, the map with an AEP of 1 percent is used to depict this event.

Before this study, emergency responders in North Adams and Williamstown 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, 1981, 1983). A second source of information is the Hoosic River streamgage from which current (2014) and historical (since 1940) river stage and discharges, including annual peak flows, can be obtained (U.S. Geological Survey, 2014). A third source of flood-related information is AHPS, which displays the observed USGS river stage data from the Hoosic River streamgage and also issues forecasts of stage for the streamgage (National Weather Service, 2014).

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 for an 8-mile reach of the Hoosic River in North Adams and Williamstown, Mass., from the confluence with the North Branch Hoosic River to the Vermont State line. This report also describes the application of flow frequency analyses to the hydraulic model and the creation of a series of flood-inundation maps for the modeled section of the river. The maps cover a range in stage from 9 ft to 16.1 ft, and correspond with the 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent AEP flows that were computed based on the peak-flow record of the Hoosic River streamgage.

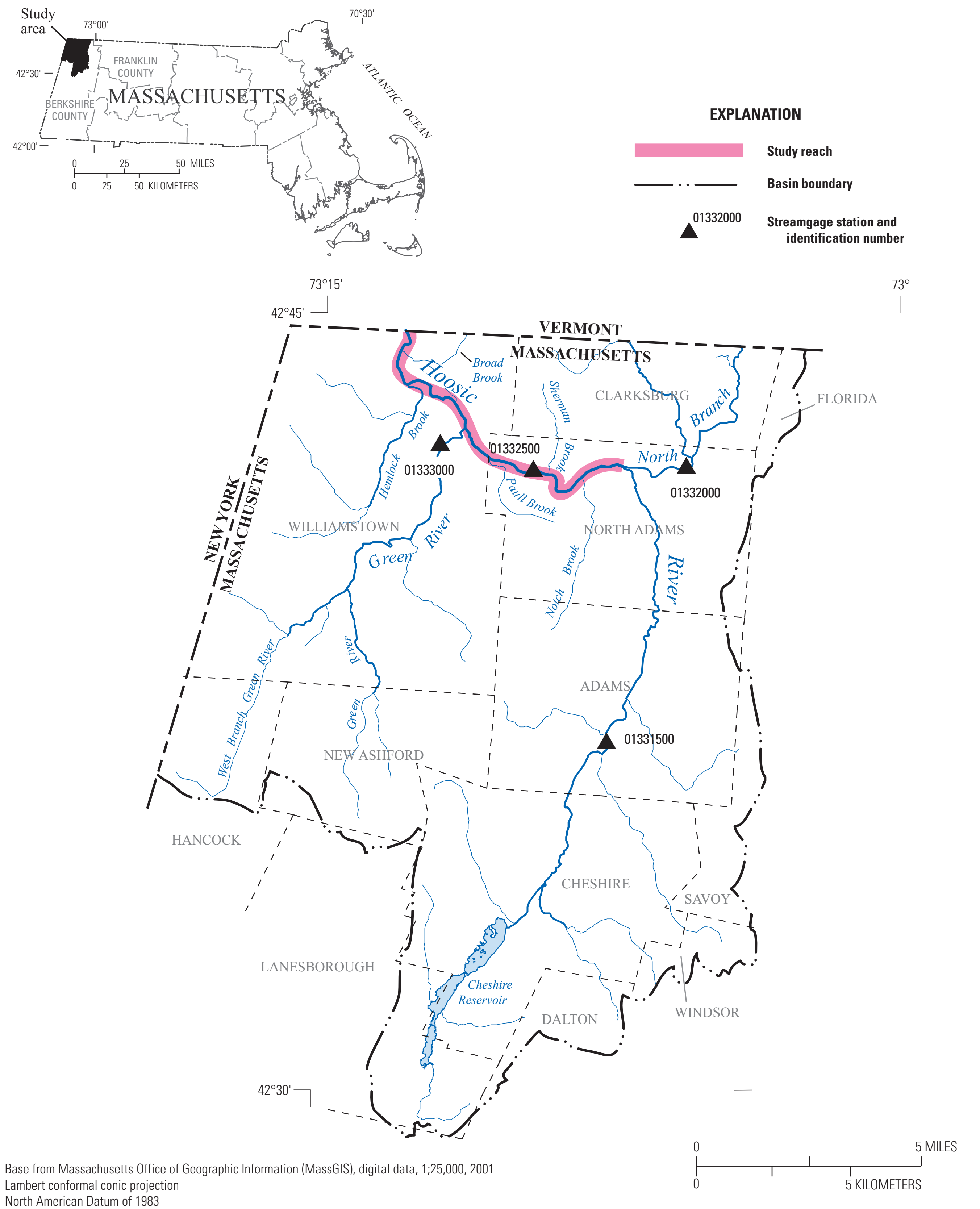

Figure 1. Location of Hoosic River study reach in North Adams and Williamstown, Massachusetts, and U.S. Geological Survey streamgages in the region.

Figure 2. Flood-inundation for a region on the Hoosic River near Williamstown, Massachusetts, corresponding to a stage of 15.2 feet at the U.S. Geological Survey streamgage 01332500.

Study Area Description

The study reach of the Hoosic River is in Berkshire County in the northwestern corner of Massachusetts. The study reach flows west from its confluence with the North Branch Hoosic River through North Adams and then northwest through Williamstown to the Vermont State line (fig. 1). There are several tributaries to the Hoosic River within the study reach: Broad Brook (10.4 square miles [mi^2]), Green River (43.0 mi^2), Hemlock Brook (14.1 mi^2), Paull Brook (3.48 mi^2), Notch Brook (3.61 mi^2), and Sherman Brook (1.70 mi^2). The Hoosic River near Williamstown, Massachusetts streamgage (01332500) is between the town centers of North Adams and Williamstown and is approximately 2.6 mi from the upstream end of the reach at the confluence with the North Branch Hoosic River, and 5.4 mi from the downstream end of the reach at the Vermont State line (fig. 1). The streamgage has a drainage area of 126 mi^2. The study reach is traversed by nine bridges and includes four low-head dams. The 2.6-mi portion of the study reach upstream from the Hoosic River streamgage to the confluence with the North Branch Hoosic River includes intermittent sections from USACE flood control structures along both banks.

Creation of Flood-Inundation Map Library

The USGS has standardized the procedures for creating flood-inundation maps for flood-prone communities so that the resulting products are similar regardless of which USGS office is responsible for the work. Tasks specific to development of the flood maps for this study of the Hoosic River are (1) collection of topographic and bathymetric data for selected cross sections and the collection 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 the 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 at http://water.usgs.gov/osw/flood_inundation.

Computation of Water-Surface Profiles

The water-surface profiles used to produce the eight 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 Hoosic River streamgage which has been in operation since 1940 (fig. 1; table 1). The Hoosic River streamgage is about 100 ft upstream from a low-head dam and 1,000 ft downstream from a footbridge over the Hoosic River at the intersection of State Route 2 and Phelps Avenue in North Adams. The river stage is measured every 15 minutes, transmitted hourly via satellite, and is available by the USGS (U.S. Geological Survey, 2014). River stage data from this streamgage are referenced to a local datum, but

Table 1. Information about the U.S. Geological Survey streamgage Hoosic River near Williamstown, Massachusetts (01332500).

[Streamgage location is shown in figure 1. mi^2, square miles; °, degrees; ′, minutes; ″, seconds; NAVD 88, North American Vertical Datum of 1988; ft^3/s, cubic feet per second]

Station information	
Station name	**Hoosic River near Williamstown, Massachusetts**
Station number	01332500
Drainage area	126 mi^2
Latitude	42°42′01″
Longitude	73°09′34″
Period of peak-flow record, in water years[1]	1941–2013
Maximum recorded stage; gage datum elevation; date	14.58 ft; 630.03 feet above NAVD 88; August 28, 2011[2]
Maximum discharge; date	14,900 ft^3/s (estimate); 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 recorded stage was 14.85 feet on December 31, 1948, but the streamgage was 1.2 miles downstream at a different datum before June 6, 1979.

can be converted to water-surface elevations referenced to NAVD 88 by adding 615.45 ft. Continuous records of streamflow at the streamgage are computed from a stage-discharge relation (rating curve) developed through concurrent stage and streamflow measurements since June 6, 1979. Before June 6, 1979, the Hoosic River near Williamstown, Massachusetts streamgage (01332500) was 1.2 miles downstream, where a different stage-discharge relation (rating curve) would have existed. This continuous record of streamflow data is available by the USGS (U.S. Geological Survey).

Discharges that were input to the hydraulic model corresponded to the 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent AEP floods at the Hoosic River streamgage (table 2) and were obtained from Olson (2014). The estimated discharges are weighted values calculated with the USGS Weighted Independent Estimator (WIE) program (Cohn and others, 2012) that combines the at-site and regional regression estimates with the variance of these estimates. The at-site estimates for the Hoosic River streamgage, which were based on 71 years of record (water years 1941–2011), 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 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. The regional regression estimates (Olson, 2014) use the drainage area (in square miles), the area of a basin covered by wetlands and open water (percent), and the basin-wide mean annual precipitation (inches) to estimate flow statistics. Peak flows at the streamgage were transferred 2.6 mi upstream and 5.4 mi downstream from the streamgage (the study reach limits) 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, equations 19 and 20).

The tropical storm Irene (August 28, 2011) peak flow (14,900 ft^3/s) was transferred upstream and downstream from the Hoosic River streamgage with a drainage-area ratio method using the following equation:

$$Q_u = Q_g \left(\frac{A_u}{A_g} \right)^e , \qquad (1)$$

where

- Q_u is the streamflow at the ungaged location, in cubic feet per second;
- Q_g is the streamflow at the gaged location, in cubic feet per second;
- A_u is the drainage area at the ungaged location, in square miles;
- A_g is the drainage area at the gaged location, in square miles; and
- e is the exponent of the drainage-area-only equations (Olson, 2014).

The e values are as follows: 20-percent AEP, 0.855; 10-percent AEP, 0.847; 4-percent AEP, 0.838; 2-percent AEP, 0.833; 1-percent AEP, 0.827; 0.5-percent AEP, 0.822; and 0.2-percent AEP, 0.816.

The peak flow of 14,900 ft^3/s is close to the 1-percent AEP at the Hoosic River streamgage, so an "e" value of 0.827 from Olson's (2014, equation 27) drainage-area-only equation was used in this drainage-area ratio method. The Hoosic River's estimated tropical storm Irene peak flows are presented in table 2. Adjustments to the estimated flows were made to account for inflows from major tributaries—Green River and Hemlock Brook (table 2). 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 Hoosic River.

Table 2. Estimated discharges for the 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-annual exceedance probabilities and the tropical storm Irene flood (August 28, 2011) at selected locations on the Hoosic River in North Adams and Williamstown, Massachusetts.

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

Location on Hoosic River	Drainage area (mi^2)	Estimated discharge, in ft^3/s, for the annual exceedance probabilities (percent)							Peak flow August 28, 2011 (tropical storm Irene) flood (ft^3/s)
		20	10	4	2	1	0.5	0.2	
Massachusetts/Vermont State line	204	9,300	11,600	15,000	17,800	20,800	24,100	29,100	22,600
Upstream from Hemlock Brook	179	8,260	10,400	13,500	16,000	18,800	21,900	26,500	20,100
Upstream from Green River	133	6,350	8,060	10,600	12,700	15,000	17,700	21,600	15,600
USGS streamgage Hoosic River near Williamstown (01332500)	126	6,080	7,730	10,200	12,200	14,500	17,100	20,900	14,900

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 (15 centimeters) 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, 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 88 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 during September and October 2012 and September 2013. 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). Nine measurements of the elevations at two National Geodetic Survey benchmark (permanent identification numbers MZ0369 and MZ0373) locations in northern Berkshire County, Mass., differed from their known elevations by 0.006 to 0.181 ft. The median difference of these nine RTK DGPS measurements from the known elevations of these two benchmarks was 0.089 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). Thirteen structures, consisting of nine bridges (Brown Street, a railroad bridge, State Route 2 in two places, Protection Avenue, a footbridge, Ashton Avenue, Cole Avenue, and State Route 7) and four low-head dams, have the potential to affect water-surface elevations during floods along the stream reach. Several levees in North Adams also have the potential to affect water-surface elevations during floods. Bridge-geometry and cross-section data were obtained from field surveys by USGS personnel during the summer of 2013.

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 upstream end of the reach is characterized by lined concrete channels, leading to low channel *n*-values ranging from 0.03 to 0.04. Much of the reach downstream from the concrete-lined channel is made up of cobbles and has *n*-values mostly between 0.04 and 0.05, with a few values as high as 0.066 in the vicinity of the railroad bridge, which has larger boulders interspersed. Although the reach is somewhat urban, overbanks are mostly in the forested riparian corridor and vary from 0.07 to 0.09 depending on the openness of the section. Much of the overbank can be characterized by dense overhanging hardwood vegetation. Slopes vary from 0.007 in the upper one-third of the reach and closer to 0.001 to 0.002 in the lower two-thirds of the reach. Bankfull top widths typically are between 100 and 120 ft wide. 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 0.03 to 0.066 for the main channel and from 0.065 to 0.09 for the overbank areas modeled in this analysis.

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 0.0015. The HEC–RAS model was calibrated to the current (2014) stage-discharge relation (rating curve 41) at the Hoosic River streamgage, and to documented high-water marks from the tropical storm Irene in August 2011 (Bent and others, 2013). Model calibration 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.

Differences between surveyed and modeled elevations of HWMs in the study reach for the August 2011 flood were less than 0.8 ft for 14 of the 15 HWMs (table 3). The remaining HWM, with a difference of 1.42 ft between the surveyed and simulated elevations, was not used to calibrate the model because of its incongruity with surrounding information. It is somewhat common 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, as is the case with HWM–MA–HOOSIC–263. 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 eight flood stages between 9.0 ft and 16.1 ft as referenced to the local datum of the Hoosic River streamgage (01332500; table 4). The 9.0- and 16.1-ft stages correspond to elevations of 624.45 ft and 631.59 ft NAVD 88, respectively. Stages 10.9 to 16.1 ft were selected to match the flood stages with AEPs between 20 and 0.2 percent

Table 3. Calibration of hydraulic model to water-surface elevations at selected locations along the Hoosic River in North Adams and Williamstown, Massachusetts, for the tropical storm Irene (August 28, 2011) flood.

[ID, identification number; NAVD 88, North American Vertical Datum of 1988]

River station (feet)[1]	High-water mark ID[2]	High-water mark rating[2]	Surveyed water-surface elevation above NAVD 88[2] (feet)		Difference in elevation (feet)
			Surveyed	Modeled	
7,996	HWM-MA-HOOSIC-253	Good	585.28	585.42	-0.14
10,132	HWM-MA-HOOSIC-252	Excellent	587.35	587.39	-0.04
11,041	HWM-MA-HOOSIC-251	Good	593.05	592.44	0.61
16,345	HWM-MA-HOOSIC-256	Excellent	596.56	596.60	-0.04
16,471	HWM-MA-HOOSIC-255	Fair	597.46	596.71	0.75
23,107	HWM-MA-HOOSIC-257	Excellent	609.91	609.72	0.19
25,849	HWM-MA-HOOSIC-259	Fair	616.86	616.66	0.20
28,776	HWM-MA-HOOSIC-261	Poor	623.22	623.48	-0.26
29,103	Crest-stage gage at Hoosic River near Williamstown streamgage 01332500	Good	630.03	630.03	0.00
29,212	HWM-MA-HOOSIC-260	Fair	629.75	630.30	-0.55
31,453	HWM-MA-HOOSIC-264	Good	633.18	633.24	-0.06
31,765	HWM-MA-HOOSIC-263	Good	632.88	634.30	[3]-1.42
33,547	HWM-MA-HOOSIC-262	Unknown	636.76	636.53	0.23
37,846	HWM-MA-HOOSIC-266	Good	653.01	652.95	0.06
38,574	HWM-MA-HOOSIC-265	Excellent	662.21	661.92	0.29

[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] From Bent and others (2013).

[3] This high-water mark is questionable because it is incongruously lower than a mark 300 ft downstream. The simulated water surface closely matches high-water marks upstream and downstream from this mark. Furthermore, it is conceivable that field crews got a mark that was below the final water-surface elevation. For this reason, this mark was not used to calibrate the model.

Table 4. Stage, elevation, discharge, and annual exceedance probabilities at the Hoosic River near Williamstown, Massachusetts, streamgage (01332500) for profiles mapped on the Hoosic River in North Adams and Williamstown.

[NAVD 88, North American Vertical Datum of 1988; NA, not applicable]

Grid identification	Stage (feet)	Elevation, above NAVD 88 (feet)	Discharge (cubic feet per second)	Annual exceedance probability (percent)
HoosicMA_09	9.0	624.45	3,420	NA
HoosicMA_10	10.0	625.45	4,780	NA
HoosicMA_11	10.9	626.39	6,080	20
HoosicMA_12	11.8	627.30	7,730	10
HoosicMA_13	12.9	628.40	10,200	4
NA	13.7	629.15	12,200	2
HoosicMA_14	14.0	629.45	13,420	NA
NA	14.5	629.91	14,500	1[1]
HoosicMA_15	15.2	630.66	17,100	0.5
HoosicMA_16	16.1	631.59	20,900	0.2

[1] The map with a stage of 14.5 feet has an annual exceedance probability of 1 percent and thus depicts the flood of August 28, 2011.

(floods with recurrence intervals from 5 to 500 years), and thus do not fall at exact 1-ft increments (table 4). The 9-ft stage is approximately bankfull and is defined by the NWS AHPS as the minor flood stage. The 16.1-ft stage is 3 ft higher than the NWS AHPS defined major flood stage of 13.0 ft for the streamgage, and exceeds the highest recorded stage at the streamgage—the August 28, 2011 peak of 14.58 ft. Stages corresponding to the discharges computed by flood-frequency analyses were obtained from the current (2014) stage-discharge relation (rating curve 41) for the Hoosic River streamgage, which includes flood stages from 5.13 ft to 15.00 ft (or 16.0 to 16,000 ft^3/s). Stages for discharges that exceeded the rating curve (AEPs of 0.5 and 0.2 percent) were obtained from the calibrated model. Discharges were transferred upstream and downstream from the streamgage using the drainage area methods discussed previously in the “Hydrology” section. The model-simulated water-surface elevations for 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent AEP floods are tabulated in appendix 1.

Flood-Inundation Maps

Flood-inundation maps were created in a GIS for the eight water-surface profiles by combining the profiles and DEM data. The maps depict the flood plain boundaries of the 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent AEP floods for the Hoosic River streamgage (table 4). Two additional maps for stages lower than for the 20-percent AEP flood (9.0 and 10.0 ft, gage datum) were created so that the NWS-designated minor flood stage would be covered by the map series. The tropical storm Irene flood of August 28, 2011 had an AEP of 1 percent and thus is depicted by the map with a stage of 14.4 ft and a 1-percent AEP.

The DEM data were derived from the lidar data described in the “Topographic and Bathymetric Data” section and have an estimated vertical accuracy of plus or minus 1 ft. Estimated flood-inundation boundaries for each simulated profile were developed with HEC–GeoRAS software (U.S. Army Corps of Engineers, Hydrologic Engineering Center, 2009), which allows the preparation of geometric data for import into HEC–RAS and processes simulation results exported from HEC–RAS (U.S. Army Corps of Engineers, Hydrologic Engineering Center, 2010). Shapefile polygons and depth grids of the inundated areas for each profile were modified, as required, in the ArcMap application of ArcGIS (Esri, 2014) to ensure a hydraulically reasonable transition of the flood boundaries between modeled cross sections.

The flood-inundation areas are overlaid on high-resolution, geo-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. Areas protected by levees are shown as disconnected polygons of a different color. The user can turn on and off the area of uncertainty due to levees. Bridge surfaces are shown as non-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 following section.

Flood-Inundation Map Delivery

A flood-inundation mapping science Web site at 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 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. 2). The flood-inundation maps are displayed in sufficient detail so that preparations for flooding and decisions for emergency response can be done efficiently. In addition to the capability of viewing and printing maps through the USGS mapping application, shapefiles depicting flood plain boundaries for the 1- and 0.2-percent AEP floods are available through links presented in appendix 2. Note that separate shapefiles for each AEP are available for the areas protected by the levee and indicate the areas that would flood only if the levees were to fail.

A link on the mapping application Web site connects to the USGS National Water Information Service (U.S. Geological Survey, 2014), which presents the current (real-time) stage and streamflow at the Hoosic River near Williamstown, Massachusetts streamgage (01332500) to which the inundation maps are referenced. A second link connects to the NWS AHPS Web site (National Weather Service, 2014) so that the user can obtain applicable information on forecasted peak stage.

Disclaimer for Flood-Inundation Maps

The 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. The flood boundaries shown were estimated on the basis of flood stages and streamflows at the Hoosic River streamgage. 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 2012. Unique meteorological factors (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. 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 or ice jams. The accuracy of the floodwater extent portrayed on these maps will vary with the accuracy of the DEM used to simulate the land surface.

If this series of flood-inundation maps is used in conjunction with NWS river forecasts, the user should be aware of additional uncertainties that may be inherent or factored into NWS forecast procedures. The NWS uses forecast models to estimate the quantity and timing of water flowing through selected stream reaches in the United States. These forecast models (1) estimate the amount of runoff generated by precipitation and snowmelt, (2) simulate the movement of floodwater as it proceeds downstream, and (3) predict the flow and stage (and water-surface elevation) for the stream at a given location (NWS AHPS forecast point; National Weather Service, undated) throughout the forecast period (every 6 hours and 3 to 5 days out in many locations).

Summary

A series of eight digital flood-inundation maps were developed in cooperation with the Federal Emergency Management Agency (FEMA) for the 8-mile reach of the Hoosic River from the confluence with the North Branch Hoosic River to the Vermont State line in North Adams and Williamstown, Massachusetts. 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 (2014) stage-discharge relation (rating curve 41) at the U.S Geological Survey (USGS) streamgage Hoosic River near Williamstown, Mass. (01332500), and to the peak water-surface elevations (high-water marks) along the 8-mile reach from the August 28, 2011, flood.

The hydraulic model was used to compute eight water-surface profiles for flood stages referenced to the streamgage datum and ranging from 9 feet (ft), which is near bankfull and equals the National Weather Service (NWS)-defined minor flood stage, to 16.1 ft, which exceeds the maximum recorded stage (14.58 ft) and the NWS major flood stage (13 ft). Modeled water-surface profiles correspond to floods with 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent annual exceedance probabilities and to the August 28, 2011, flood, making them consistent with FEMA flood recovery maps as well.

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, 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). In addition, shapefiles depicting the 1- and 0.2-percent flood boundaries are available online as a part of 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 Hoosic River streamgage, and forecasted flood stage data from the NWS Advanced Hydrologic Prediction Service, will help to guide the general public in taking individual safety precautions and will provide emergency management personnel with a tool to efficiently manage emergency flood operations and postflood recovery efforts. The flood-inundation maps are non-regulatory, 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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Appendix 1. Water-Surface Elevations at Modeled Cross Sections Along the Hoosic River, North Adams and Williamstown, Massachusetts

Table 1–1. Water-surface elevations for the 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 each modeled cross section along the Hoosic River, North Adams and Williamstown, 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. NAVD 88, North American Vertical Datum of 1988]

Cross-section ID (feet)	Water-surface elevation, in feet above NAVD 88								
	Annual exceedance probability							August 28, 2011, flood	1-percent AEP floodway
	20-percent	10-percent	4-percent	2-percent	1-percent	0.5-percent	0.2-percent		
43,055	679.34	680.56	682.27	682.78	683.96	685.25	689.13	684.21	684.16
42,774	678.33	679.63	681.40	681.89	683.02	684.24	687.69	683.30	683.32
42,679	678.25	679.57	681.36	681.86	683.01	684.27	687.50	683.30	683.32
42,614	678.00	679.28	681.02	681.07	681.93	682.50	683.20	682.23	682.40
42,461	675.83	676.92	678.38	679.60	681.29	681.94	683.20	681.76	680.35
42,204	673.15	674.12	675.48	676.46	677.55	681.16	682.34	677.70	677.57
42,117	671.33	672.48	674.05	675.16	675.96	676.97	678.22	676.13	675.95
42,075	670.89	672.12	673.68	674.79	675.95	676.96	678.22	676.12	675.95
41,841	670.35	671.62	673.25	674.41	675.64	676.71	678.06	675.83	675.64
41,632	669.75	670.98	672.56	673.67	674.75	675.79	677.13	674.93	674.75
41,188	668.30	669.54	671.13	672.22	673.24	674.13	675.04	673.41	673.24
40,291	664.68	665.67	666.87	667.71	668.50	669.23	670.22	668.63	668.49
39,498	661.80	662.37	663.06	663.52	664.10	664.71	665.72	664.19	664.10
38,624	657.58	658.60	660.00	661.03	662.05	663.14	664.67	662.22	662.01
38,332	655.84	656.85	658.24	659.33	660.35	661.43	662.96	660.52	660.27
38,212	654.70	655.67	656.98	657.94	658.61	659.27	660.19	658.72	658.45
38,152	654.43	655.44	656.80	657.81	658.52	659.29	660.42	658.64	658.34
38,088	654.03	654.98	656.24	657.17	657.61	657.90	657.91	657.67	657.38
37,982	650.12	650.69	651.63	652.26	653.10	653.96	655.18	653.24	653.37
37,808	648.85	649.59	650.90	651.62	652.71	653.74	655.20	652.87	652.86
37,550	647.49	648.36	650.05	650.71	651.94	653.12	654.90	652.12	650.99
37,373	647.64	648.60	650.17	650.87	652.13	653.28	654.92	652.31	650.80
37,230	647.24	648.19	649.63	650.22	651.49	652.61	654.21	651.67	650.06
37,155	646.97	647.91	649.47	649.99	651.20	652.22	653.69	651.36	649.61
37,108	646.91	647.84	649.40	649.91	651.11	652.13	653.61	651.27	649.41
36,969	637.66	638.61	639.91	640.88	641.91	643.01	644.93	642.08	641.91
36,776	636.97	638.04	639.48	640.54	641.65	642.85	644.94	641.84	641.65
36,286	635.48	636.56	638.01	639.08	640.19	641.39	643.72	640.37	640.19

Table 1–1. Water-surface elevations for the 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 each modeled cross section along the Hoosic River, North Adams and Williamstown, 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. NAVD 88, North American Vertical Datum of 1988]

Cross-section ID (feet)	Water-surface elevation, in feet above NAVD 88								
	Annual exceedance probability							August 28, 2011, flood	1-percent AEP floodway
	20-percent	10-percent	4-percent	2-percent	1-percent	0.5-percent	0.2-percent		
35,572	633.61	634.86	636.49	637.66	638.82	640.09	642.75	639.02	638.82
34,575	632.33	633.58	635.19	636.34	637.46	638.74	641.74	637.66	637.46
33,547	631.21	632.43	634.05	635.21	636.32	637.67	641.08	636.53	636.32
32,915	630.59	631.81	633.41	634.55	635.62	636.87	640.43	635.82	635.62
32,659	630.26	631.47	633.06	634.19	635.22	636.49	640.21	635.41	635.22
32,513	630.17	631.39	632.99	634.12	635.15	636.36	640.11	635.34	635.15
32,432	630.06	631.28	632.87	633.99	635.00	636.11	639.92	635.20	635.00
32,324	629.70	630.93	632.54	633.67	634.68	635.98	639.85	634.88	634.68
32,195	629.65	630.90	632.52	633.66	634.67	635.98	640.00	634.87	634.67
31,809	629.35	630.59	632.18	633.30	634.26	635.54	639.88	634.45	634.26
31,578	628.89	630.09	631.64	632.72	633.76	634.99	639.12	633.95	633.77
31,483	628.67	629.82	631.26	632.23	633.09	634.18	635.36	633.26	633.10
31,360	628.47	629.62	631.07	632.07	633.04	634.14	635.35	633.20	633.04
30,261	627.56	628.61	629.99	631.00	632.08	633.48	634.98	632.23	632.08
30,112	627.43	628.46	629.80	630.79	631.89	633.36	634.87	632.08	631.89
30,044	627.36	628.39	629.74	630.75	631.87	633.05	634.62	632.06	631.87
29,943	627.21	628.22	629.47	630.35	631.24	632.14	633.30	631.39	631.24
29,232	626.53	627.47	628.63	629.44	630.30	631.18	632.33	630.44	630.30
29,104	626.39	627.30	628.40	629.15	629.91	630.66	631.59	630.03	629.91
28,976	618.36	619.56	620.96	621.92	622.82	624.31	625.34	623.70	622.82
28,699	617.55	618.83	620.35	621.40	622.35	624.04	625.15	623.41	622.34
28,289	616.21	617.42	618.86	619.83	620.85	623.33	624.48	622.67	620.85
27,187	613.89	615.36	617.28	618.67	619.97	622.98	624.13	622.33	619.97
26,272	612.43	614.09	616.30	617.81	619.18	622.53	623.63	621.92	619.18
26,115	612.07	613.44	615.14	616.21	617.05	620.80	621.09	620.55	617.05
26,039	611.97	613.32	614.94	615.94	616.77	617.83	618.87	617.10	616.88
25,949	611.90	613.28	614.95	616.00	616.88	617.78	618.78	617.09	616.77
24,587	609.41	610.37	611.52	612.19	612.91	613.60	614.50	613.06	612.91
23,828	607.87	608.93	610.01	610.51	611.13	611.80	612.73	611.28	611.13
22,834	604.51	605.54	606.94	607.96	608.88	609.83	611.01	609.12	608.89
22,245	602.90	603.82	604.94	605.66	606.36	607.20	608.42	606.60	606.36

Table 1–1. Water-surface elevations for the 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 each modeled cross section along the Hoosic River, North Adams and Williamstown, 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. NAVD 88, North American Vertical Datum of 1988]

Cross-section ID (feet)	Water-surface elevation, in feet above NAVD 88								
	Annual exceedance probability							August 28, 2011, flood	1-percent AEP floodway
	20-percent	10-percent	4-percent	2-percent	1-percent	0.5-percent	0.2-percent		
21,195	601.03	601.90	603.04	603.96	604.96	606.13	607.63	605.40	604.96
20,375	599.54	600.44	601.86	603.02	604.29	605.63	607.23	604.84	604.29
19,207	598.46	599.76	601.50	602.76	604.07	605.45	607.08	604.66	604.07
18,946	598.30	599.66	601.44	602.72	604.04	605.42	607.06	604.63	604.04
18,738	597.99	599.36	601.16	602.44	603.78	605.17	606.79	604.37	603.78
17,875	596.53	597.86	599.60	600.82	602.10	603.43	604.83	602.66	602.10
17,129	595.44	596.58	598.07	599.12	600.25	601.52	602.57	600.78	600.25
16,943	595.25	596.35	597.79	598.81	599.91	601.15	602.12	600.43	599.91
16,868	594.52	595.38	596.47	597.22	598.01	598.93	599.95	598.42	598.01
16,777	594.33	595.13	596.10	596.74	597.37	598.12	598.36	597.71	597.37
16,734	594.29	595.09	596.05	596.69	597.32	598.05	598.86	597.66	597.32
16,688	594.17	594.92	595.82	596.37	596.89	597.49	597.91	597.18	596.89
16,586	594.06	594.77	595.59	596.09	596.53	597.05	597.27	596.73	596.53
16,487	594.00	594.70	595.52	596.02	596.50	597.02	597.86	596.71	596.50
15,888	593.20	593.84	594.65	595.25	595.92	596.68	597.65	596.24	595.92
14,702	591.45	592.06	592.95	593.67	594.50	595.43	596.48	594.91	594.50
13,123	588.53	589.55	590.86	591.88	592.95	594.11	595.26	593.46	592.95
12,276	588.05	589.16	590.53	591.59	592.69	593.87	595.01	593.20	592.69
11,041	586.83	588.08	589.61	590.76	591.92	593.14	594.23	592.45	591.92
10,614	584.95	586.22	587.80	589.21	590.56	591.99	593.03	591.19	590.56
10,449	584.18	585.44	586.94	587.96	589.00	590.03	591.04	589.47	588.99
10,337	583.95	585.17	586.57	587.51	588.42	589.28	589.89	588.82	588.42
10,216	582.92	584.03	585.26	586.11	587.00	587.99	589.45	587.46	586.99
9,356	581.76	582.86	584.11	585.09	586.16	587.30	589.01	586.74	586.15
8,312	580.08	581.21	582.62	583.79	585.01	586.31	588.16	585.72	584.99
7,255	577.86	579.25	581.10	582.51	583.92	585.36	587.35	584.72	583.89
5,995	576.05	577.59	579.60	581.09	582.53	584.00	585.92	583.35	582.50
5,158	574.87	576.40	578.37	579.82	581.21	582.61	584.45	581.99	581.16
3,853	572.93	574.36	576.20	577.55	578.81	580.07	581.63	579.52	578.72
2,448	570.68	571.97	573.64	574.86	576.04	577.25	578.55	576.72	575.84
1,983	569.52	570.72	572.27	573.44	574.61	575.80	576.94	575.27	574.25
833	566.58	567.83	569.52	570.81	572.09	573.36	573.92	572.79	571.01
490	566.13	567.40	569.09	570.37	571.64	572.91	573.30	572.34	570.40

Appendix 2. Shapefiles for the Hoosic River Study Reach in North Adams and Williamstown, Massachusetts, Including Flood Plain Boundaries for the 1- and 0.2-Percent Annual Exceedance Probability (AEP)

[These files can be accessed at http://dx.doi.org/10.3133/sir20145236]

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Publishing support by:
The Pembroke and Rolla Publishing Service Center.

Lombard and Bent—**Flood-Inundation Maps for the Hoosic River, North Adams and Williamstown, Massachusetts**—Scientific Investigations Report 2014–5236

Printed on recycled paper

ISSN 2328-0328 (online)
http://dx.doi.org/10.3133/sir20145236