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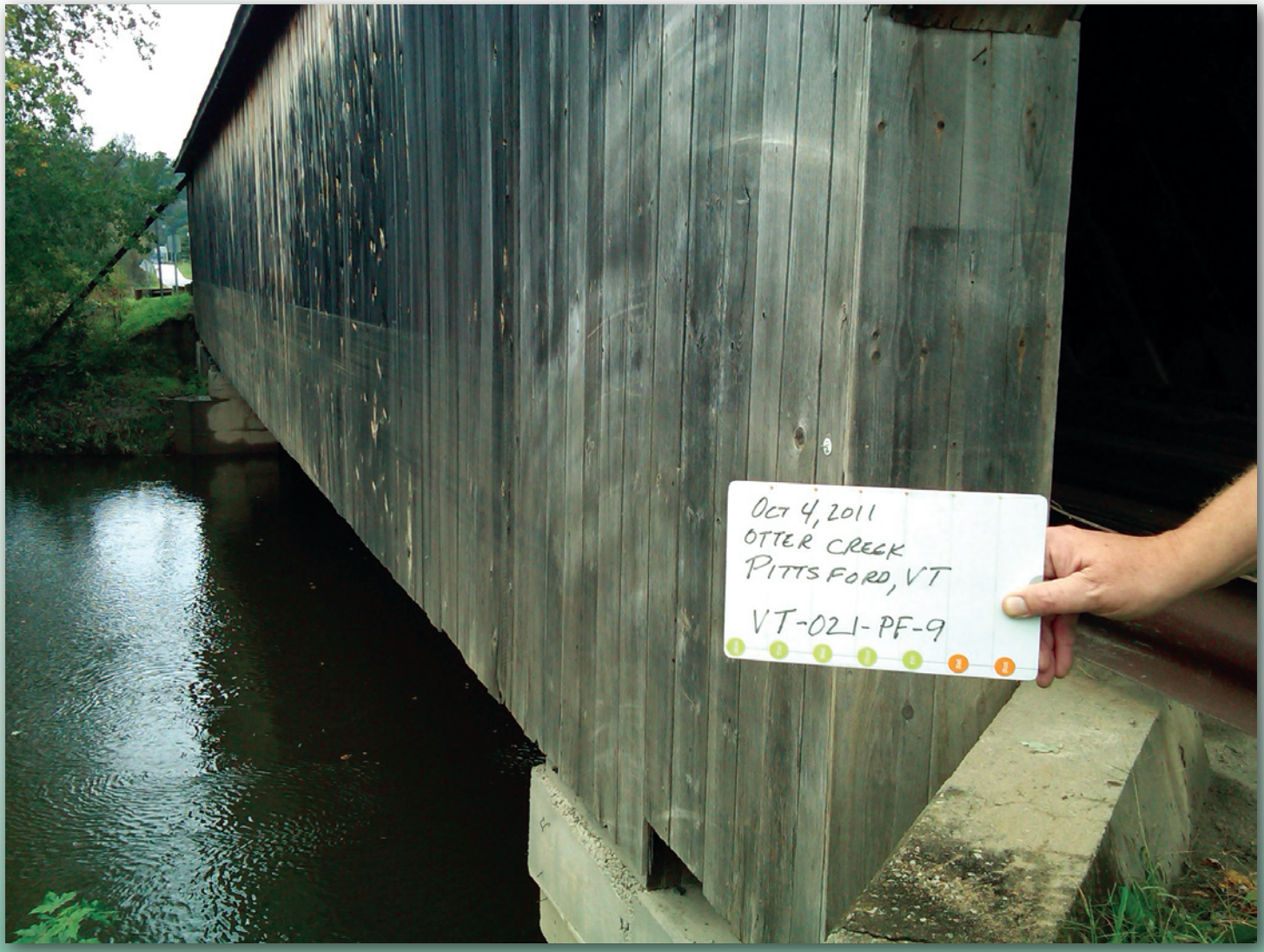
High-Water Marks From Flooding in Lake Champlain from April through June 2011 and Tropical Storm Irene in August 2011 in Vermont



Data Series 763

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

Cover. Covered bridge over Otter Creek showing a high-water mark (silt line) from tropical storm Irene, August 29. 2011.

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By Laura Medalie and S.A. Olson

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

U.S. Geological Survey
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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
	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, unless otherwise noted, 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) and to the Vermont State Plane Coordinate System.

Abbreviations

FEMA	Federal Emergency Management Agency
GPS	Global Positioning System
HWM	high-water mark
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
PDA	personal digital assistant
USGS	U.S. Geological Survey

High-Water Marks from Flooding in Lake Champlain from April through June 2011 and Tropical Storm Irene in August 2011 in Vermont

By Laura Medalie and S.A. Olson

Abstract

The U.S. Geological Survey, in cooperation with the Federal Emergency Management Agency, identified high-water marks after two floods in Vermont during 2011. Following a snowy winter, new monthly precipitation records were set in Burlington, Vermont, in April and May 2011, causing extensive flooding from April through June. The spring 2011 flooding resulted in a new record for stage (103.27 feet, referenced to the National Geodetic Vertical Datum of 1929) at the Lake Champlain at Burlington, Vt., gaging station (04294500). During August 28 and 29, 2011, tropical storm Irene delivered rainfall totals of 3 to more than 7 inches throughout Vermont, which resulted in extensive flooding and new streamflow records at nine streamgaging stations. Four presidential declarations of disaster were made following the 2011 flood events in Vermont.

Thirty-nine high-water marks were identified and flagged to mark the highest levels of Lake Champlain from the May 2011 flooding, and 1,138 high-water marks were identified and flagged along Vermont rivers after flooding from tropical storm Irene in August 2011. Seventy-four percent of the high-water marks that were flagged were later found and surveyed to the North American Vertical Datum of 1988.

Introduction

A snowy winter capped by a snow storm that set a record for the greatest total snowfall of any March storm (in Burlington, Vermont), followed by monthly precipitation records set in April and May 2011 (also in Burlington) caused historic flooding to Lake Champlain. Just three months later, in August, more record-breaking rainfall and damaging winds from hurricane Irene (downgraded to a tropical storm before entering New England) resulted in extensive destruction and millions of dollars of damages in the eastern United States. During the spring event, nine streamgages on five rivers plus two Lake Champlain gaging stations were at or above National Weather Service flood stage for as much as 68 days. During tropical storm Irene, eight streamgages in Vermont measured new streamflow peaks of record, which equaled or exceeded the 1-percent annual exceedance probability[1] for events (U.S. Geological Survey, 2011).

Presidential declarations of major disasters were made in June, July, and November 2011 (Federal Emergency Management Agency (FEMA) directives FEMA–1995–DR, FEMA–4001–DR, and FEMA–4043–DR) under the Robert T. Stafford Disaster Relief and Emergency Assistance Act (Stafford act)[2] in response to the severe storms and flooding during April and May 2011. Responding to the spring flooding, declarations were requested by Governor Peter Shumlin for individual assistance for 10 counties, public assistance for 11 counties, and hazard mitigation statewide.

Following tropical storm Irene, the President declared major disaster FEMA–4022–DR for the State of Vermont on September 1, 2011. This declaration and its subsequent amendments authorized individual assistance for 12 counties, public assistance for all 14 counties, and hazard mitigation statewide. Table 1 provides a partial list of damages and responses to the two events.

High-water marks (HWMs) from major storm events provide evidence of the highest water-surface elevations reached by a flood. This information is necessary for documenting the magnitude and extent of flooding to support State and local governments and FEMA in making eligibility determinations under the Public Assistance and Individual Assistance Grant Programs. Data from HWMs also are used to determine appropriate hazard mitigation measures to minimize flood losses in future disasters, to prioritize and allocate disaster funding, and to support recovery activities authorized by the Stafford act. To support flood recovery efforts from the two major flood events in 2011 and carry out the Hazard Mitigation

[1]The 1-percent annual exceedance probability has a 1 in 100 chance of being equaled or exceeded in any 1 year and has an average recurrence interval of 100 years. It is often referred to as the "100-year flood."

[2]Robert T. Stafford Disaster Relief and Emergency Assistance Act, Public Law 93–288 (1974; codified as amended at 42 U.S.C. §§ 5121–5207).

Table 1. Damages and responses to the floods in Vermont in 2011: in Lake Champlain April through June and statewide due to tropical storm Irene in August.

[Data are from Lake Champlain Basin Program (2012). FEMA, Federal Emergency Management Agency; VTrans, Vermont Agency of Transportation)]

April through June 2011 Lake Champlain flood	Tropical storm Irene
Damages	
419 homes damaged and 24 destroyed in Vermont	Damage includes 30,000 homes, 500 mobile homes, 600 historic buildings, 500 miles of state roads, 200 miles of railroads, 1,000 culverts, 200 bridges
All-time high phosphorus loading to Lake Champlain	34 bridges closed
	Vermont State Government shut down and flooded out of the Waterbury complex[1]
Responses	
In Vermont, FEMA awarded $1.8 million in individual assistance and $8.6 million in public assistance	More than 7,000 individuals registered for FEMA assistance
Road crews worked overtime to repair and establish alternative routes (hundreds of detours)	Volunteer and community response
	VTrans asked other agencies and commissions to work with towns so that VTrans could focus exclusively on state transportation infrastructure
	Established detours and restored access to communities
	Assistance from National Guard (7 states) and workers and vehicles from the Maine and New Hampshire Departments of Transportation

[1]Approximately 1,500 employees were displaced from the Waterbury complex.

Grant Program for the State of Vermont, the U.S. Geological Survey (USGS), in cooperation with FEMA under Mission Assignment 4022–DR–VT–USGS–01, identified HWMs in Vermont between August and October 2011 and arranged a contract with a consultant to obtain surveyed elevations for those HWMs (appendix 1; Dewberry, written commun., 2012). Surveyed elevations for HWMs will be used by USGS to generate flood inundation maps for selected study reaches along major flooding sources in Vermont that experienced less than 1-percent annual exceedance probability streamflows and significant damages.

Purpose and Scope

The objective of this study is to provide a quantitative record of the spring 2011 flooding of Lake Champlain in Vermont and the tropical storm Irene flood event in Vermont that will assist in implementing relief from the Stafford act for the major disaster declarations from these events. The cooperative agreement between FEMA and USGS consists of four major tasks related to this objective—the first of which is the subject of this report: locating HWMs from the flood events and surveying them into a known base datum to document the extent and the depth of flooding.

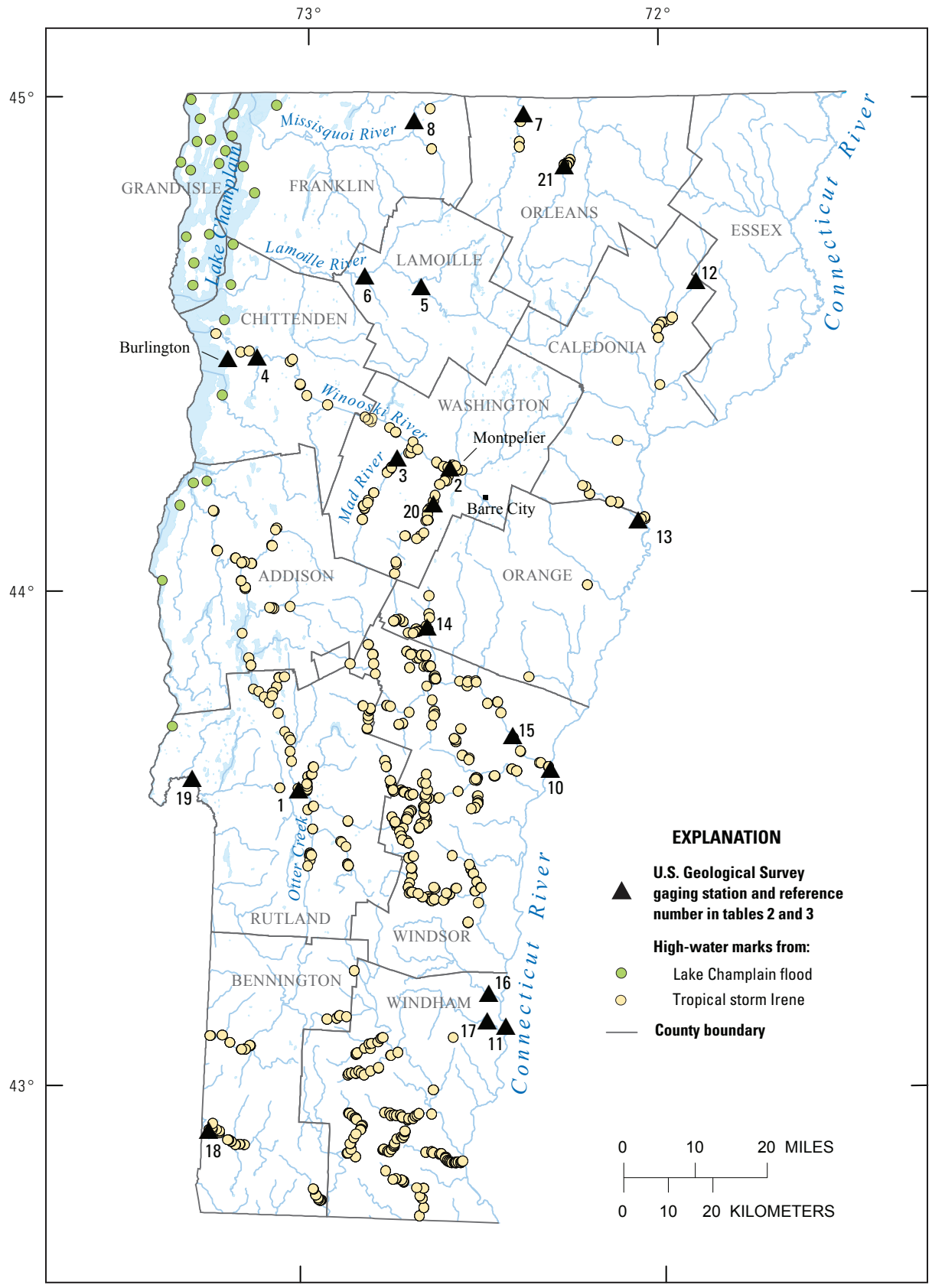
Study Area

HWMs from the April through June 2011 Lake Champlain flooding were identified and flagged in four Vermont counties (Addison, Chittenden, Franklin, and Grand Isle) during August 2011 (fig. 1). HWMs from flooding due to tropical storm Irene were flagged in all Vermont counties except Essex and Lamoille during September and October 2011, with the greatest numbers in Windsor and Windham Counties (fig. 1).

Lake Champlain Flooding from April through June 2011

Extensive flooding around Lake Champlain and northern Vermont occurred from April through June 2011. Lake Champlain levels were above the National Weather Service (NWS) flood stage of 100 feet[3] for 68 days between April 13

[3] Stages of Lake Champlain in this discussion of flooding are referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29). Elevations of HWMs surveyed for this project are referenced to the North American Vertical Datum of 1988 (NAVD 88). At the USGS Lake Champlain at Burlington gaging station (04294500), elevations presented in NGVD 29 are 0.48 ft greater than elevations in NAVD 88.



Base from Vermont Center for Geographic Information, boundary data layer (BoundaryOther_BNDHASH), 1:24,000, 2012.

Figure 1. Locations of surveyed high-water marks from flooding in Lake Champlain from April through June and from tropical storm Irene in August 2011 in Vermont.

and June 18 (fig. 2) and were above the previous maximum observed elevation of 101.86 feet (observed on April 27, 1993) for 39 of those days. The stage was set for spring flooding as the third snowiest winter on record in Burlington was capped on March 6–7, 2011, with the third largest snowfall ever recorded in Burlington and greatest total of any March storm measured at the NWS Burlington International Airport station (Vermont State Climate Office, 2011a). Precipitation records continued to be set in Burlington (Vermont State Climate Office, 2011b) in April (7.88 inches) and May (8.67 inches); all together, the wettest spring on record was observed in Burlington (19.94 inches for March through May 2011). A new record for stage, 103.27 feet (ft), was recorded on May 6 at the USGS Lake Champlain at Burlington gaging station (04294500; fig. 2). At its greatest inundation on May 6, 2011, when stage was 103.27 ft (compared to a baseline stage of 94.5 ft), the surface area of Lake Champlain increased by approximately 15 percent (66 square miles) and the volume of the water in the lake increased by 12.7 percent (867 billion gallons) (Lake Champlain Basin Program, 2011).

Also during this flood event, snowmelt compounded by extensive thunderstorm rainfall resulted in record stage levels and streamflows in several tributaries in the Lake Champlain basin and subsequent localized flooding. Barre City and Montpelier in central Vermont, in particular, suffered significant damage by flooding (WCAX–TV, 2011)—about 200 people in the area were sent to emergency shelters. Otter Creek and the Winooski, Mad, Lamoille, and Missisquoi Rivers were above flood stage for 1 to 8 days during April or May 2011 (table 2; U.S. Geological Survey, 2012).

Tropical Storm Irene

Just 3 months after the historic springtime flooding on Lake Champlain, tropical storm Irene moved through Vermont, resulting in a second presidential declaration of disaster in 2011 for Vermont, this time for the entire State. From August 28 through 29, 2011, rainfall from Irene totaled from 3 to more than 7 inches throughout Vermont (National Weather

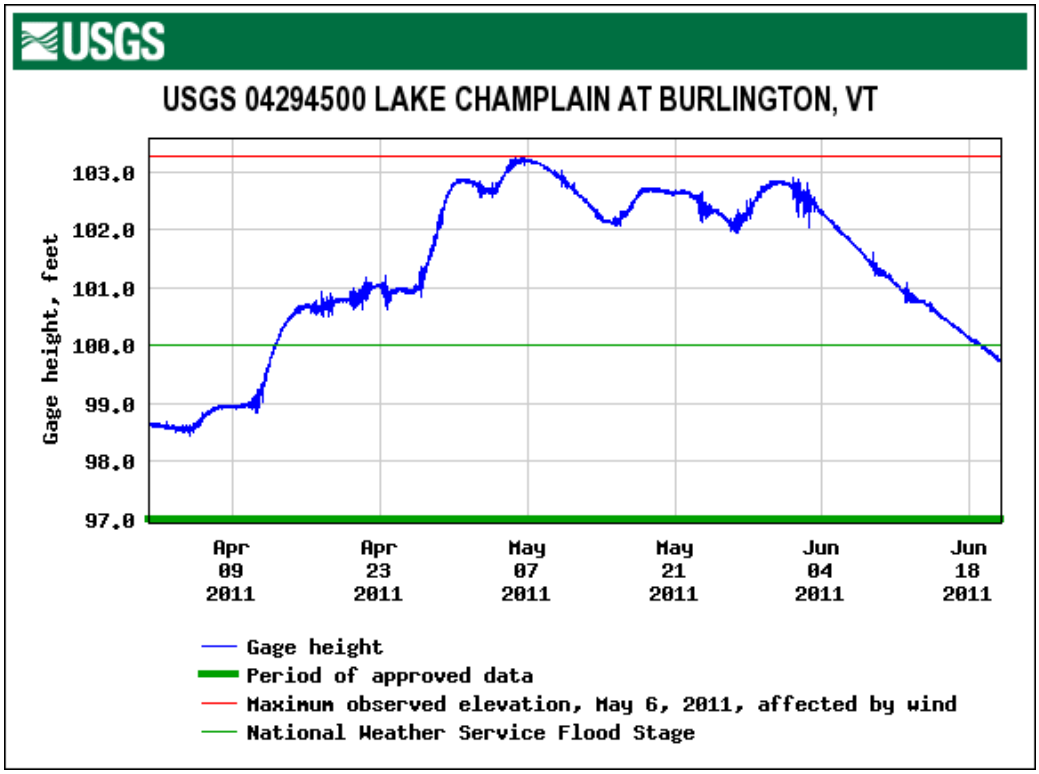


Figure 2. Gage height at the U.S. Geological Survey Lake Champlain at Burlington, Vermont, gaging station (04294500) from April 1 through June 20, 2011.

Table 2. Peak streamflows and stages compared to historical peaks for U.S. Geological Survey gaging stations with stages above National Weather Service flood stage in Vermont from April 1 through June 30, 2011.

[ft, feet; ft^3/s, cubic feet per second; mi^2, square miles; NWS, National Weather Service; USGS, U.S. Geological Survey; --, no data]

Reference number, as shown on figure 1	USGS gaging station number	USGS gaging station name	Drainage area, in mi^2	NWS flood stage, in ft	Number of days above NWS flood stage	Highest peak, from April 1 through June 30, 2011			Historical peak		
						Date	Stage, in ft	Stream discharge, in ft^3/s	Maximum stream discharge, in ft^3/s	Year	Number of years of record
1	04282000	Otter Creek at Center Rutland	307	8	5	4/13	9.35	4,880	15,700	2011	83
3	04288000	Mad River near Moretown	139	9	2	4/12	9.14	6,390	24,200	2011	84
4	04290500	Winooski River near Essex Junction	1,044	12	8	4/12	17.24	28,100	113,000	1927	84
5	04292000	Lamoille River at Johnson	310	13	3	4/27	16.97	13,800	19,000	1995	85
6	04292201	Lamoille River at Jeffersonville	489	450	6	4/27	454.21	24,600	--	--	--
7	04293000	Missisquoi River near North Troy	131	9	3	4/27	12.95	9,540	11,500	2002	80
8	04293500	Missisquoi River near East Berkshire	479	13	4	4/28	13.99	14,500	45,000	1927	95
9	04294500	Lake Champlain at Burlington	--	100	68	5/06	103.27	--	--	--	--

Service, 2011); heaviest amounts generally occurred along the storm track in the eastern axis of the State (fig. 3). New record streamflows were recorded at nine sites in or bordering Vermont and nine other sites had peak streamflows among the top four of record (table 3; U.S. Geological Survey, 2011). The magnitude of the flood, which affected 225 (88 percent) of municipalities in the State, approached that of the historic 1927 flood. Damage to the transportation sector included more than 500 miles of road and about 200 bridges of the State highway system; more than 2,000 road segments, more than 280 bridges, and about 960 culverts of the municipal road system; and more than 200 miles of railroad and 6 railroad bridges of State-owned rail system (Vermont Agency of Natural Resources, 2012). About 73,000 customers lost electric power. By November 15, 2011, significant damage to about 1,500 residences had been documented by FEMA, and 7,215 individuals and families had registered for FEMA assistance (Vermont Agency of Natural Resources, 2012). Other significant impacts were the displacement of 1,500 State employees from their workplaces, damage to two fish hatcheries, the issuance of "boil-water" notices affecting 16,590 people using about 30 public-water systems, compromised operations at 17 municipal wastewater-treatment facilities, and the filing of more than 450 farm loss claims with the U.S. Department of Agriculture to compensate for damage to approximately 20,000 acres of farmland at a loss of more than $10 million statewide (Vermont Agency of Natural Resources, 2012).

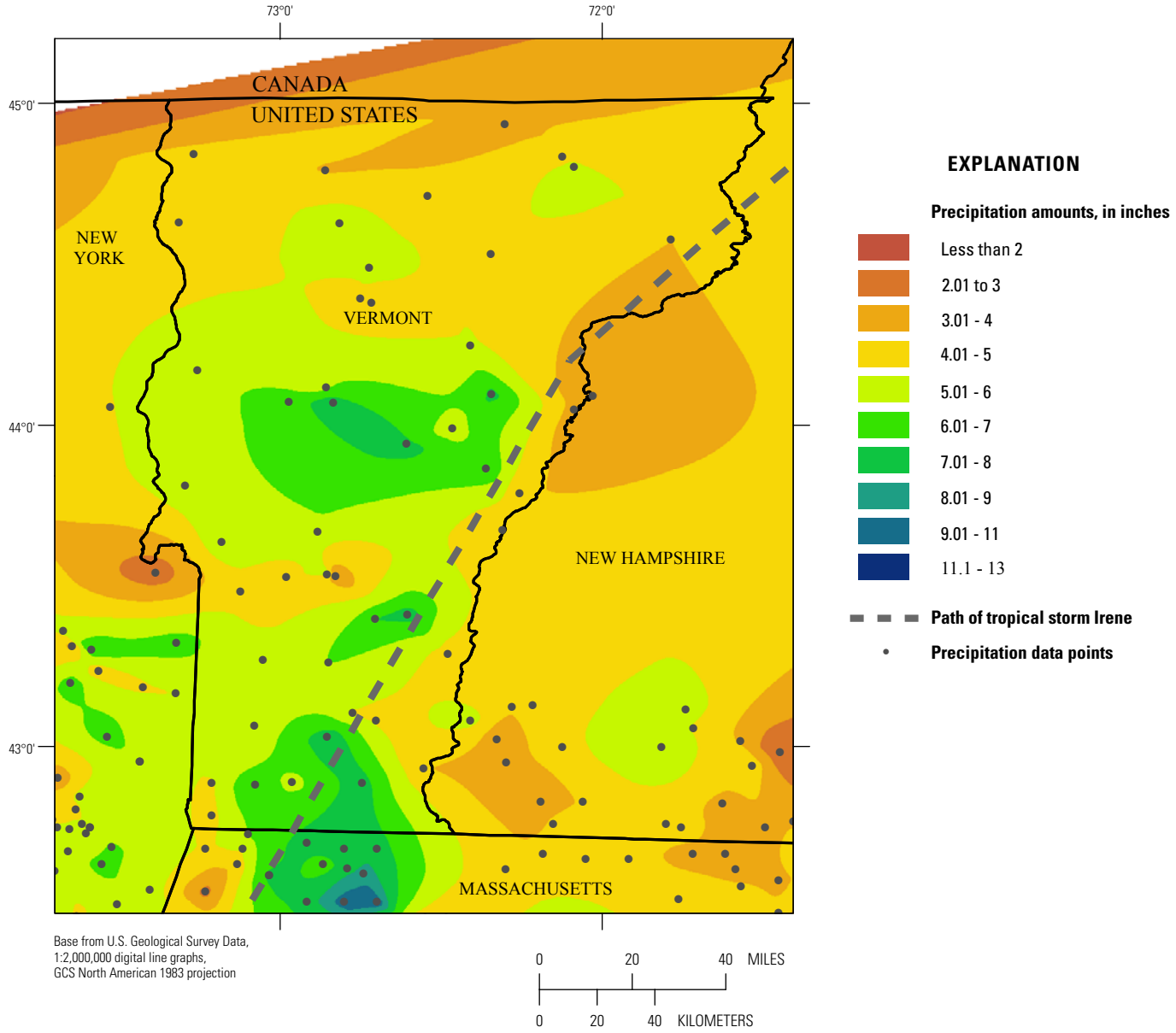


Figure 3. Rainfall totals and path of tropical storm Irene, August 28–29, 2011, in Vermont.

Table 3. Peak streamflows and stages compared to historical peaks for U.S. Geological Survey gaging stations in and near Vermont, August 27–31, 2011.

[ft, feet; ft^3/s, cubic feet per second; mi^2, square miles; USGS, U.S. Geological Survey; --, no data]

Reference number, as shown on figure 1	USGS streamgage number	USGS streamgage name	Drainage area, in mi^2	Highest peak, August 27–31, 2011				Historical peaks		
				Date	Stage, in ft	Stream discharge, in ft^3/s	Rank	Maximum streamflow discharge, in ft^3/s	Year	Number of years of record
				NEW HAMPSHIRE						
10	01144500	Connecticut River at West Lebanon	4,092	8/29	29.66	105,000	4	136,000	1927	96
11	01154500	Connecticut River at North Walpole	5,493	8/29	31.38	99,700	1	97,000	1953	69
				VERMONT						
12	01133000	East Branch Passumpsic River near East Haven	54	8/28	9.79	3,250	3	4,450	1973	50
13	01139000	Wells River at Wells River	98	8/28	9.03	5,170	2	5,970	1973	69
14	01142500	Ayers Brook at Randolph	31	8/28	15.04	3,920	1	3,480	1973	71
15	01144000	White River at West Hartford	690	8/29	28.36	90,100	2	120,000	1927	94
16	01153550	Williams River near Rockingham	112	8/28	17.94	21,300	1	11,500	1987	23
17	01154000	Saxtons River at Saxtons River	72	8/28	19.58	21,600	1	9,620	1936	52
18	01334000	Walloomsac River near North Bennington	111	8/28	12.82	9,420	1	8,450	1938	78
19	04280000	Poultney River below Fair Haven	187	8/29	23.28	12,800	2	14,800	1945	80
1	04282000	Otter Creek at Center Rutland	307	8/29	17.43	15,700	1	13,700	1938	81
2	04286000	Winooski River at Montpelier	397	8/28	19.05	14,600	4	57,000	1927	94
20	04287000	Dog River at Northfield Falls	76	8/28	17.26	22,200	1	10,600	1973	75
3	04288000	Mad River near Moretown	139	8/28	19.26	24,200	1	23,000	1927	82
4	04290500	Winooski River near Essex Junction	1,044	8/29	22.18	35,000	3	113,000	1927	82
5	04292000	Lamoille River at Johnson	310	8/29	16.54	13,100	3	19,000	1995	83
7	04293000	Missisquoi River near North Troy	131	8/29	13.93	10,900	2	11,500	2002	78
21	04296000	Black River at Coventry	142	8/29	8.20	4,070	1	3,740	1976	58

Methods

Flagging and Documenting High-Water Marks

From August 18–23, 2011, 39 HWMs from the Lake Champlain flooding in April through June 2011 were flagged in Addison, Chittenden, Franklin, and Grand Isle Counties (fig. 1). The HWMs associated with the Lake Champlain flooding marked flood crests of the lake; flooding along streams was not flagged. Marks generally were flagged at access areas or boat launches on the Vermont side of the lake.

From September 2–October 18, 2011, 30 USGS personnel identified and flagged 1,138 HWMs associated with tropical storm Irene (figs. 1 and 4). HWMs were flagged in all counties except Essex and Lamoille; the HWMs ranged from 2 in Franklin County to 435 in Windsor County. HWMs were flagged on 96 named streams or tributaries to named streams and at 6 confluences.

Each field crew consisted of at least one technician who had experience in finding and flagging HWMs according to general USGS guidelines for identifying, rating, and classifying these marks (Benson and Dalrymple, 1967). HWMs were rated according to a quantitative accuracy scale (table 4; modified from Lumia and others, 1987). A system was established for naming HWMs and recording HWM information so that data recorded by field crews would be consistent. Areas targeted for flagging HWMs after tropical storm Irene were upstream and downstream from all structures (road and railroad bridges, culverts, and dams) on all stream reaches that had experienced major flooding in the State.

Each field crew had a preprogrammed Trimble Nomad personal digital assistant (PDA) equipped with a Global Positioning System (GPS) to determine latitude and longitude information. With the identification of each unique HWM, a text file with descriptive information and the GPS location was generated and saved to the PDA. The GPS locations were stored, organized, and displayed using Trimble AgGPS EZ–Map software (Trimble Navigation Limited, 2006). At least two photographs were taken for documentation that also could be used later by the survey crews to help find the HWM. Typically, one of the photographs was at close range and the second at some distance to provide context. In some cases, a backup latitude and longitude (in addition to that saved on the PDA) was generated and either saved in paper files or in a separate electronic device.

Table 4. Quantitative scale to rate accuracy of high-water marks.

[±, plus or minus; >, greater than]

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

Surveying High-Water Marks

Surveying of HWM locations was performed by a Virginia company, Dewberry, during the 2012 field season through a contract with USGS. Dewberry found 74 percent of the HWMs that were flagged. A Microsoft Excel spreadsheet (appendix 2) listing the surveyed horizontal coordinates (referenced to the Vermont State Plane Coordinate System and the North American Datum of 1988 (NAD 83)) and vertical elevations (referenced to the North American Vertical Datum of 1988 (NAVD 88) in feet) for each HWM, and a survey report with metadata as well as a summary of the surveying segment of the project (appendix 1) were provided to the USGS (Dewberry, written commun., 2012). An explanation (for example, "missing/unable to locate" or "destroyed") was provided in the spreadsheet for the 26 percent of HWMs that were not found. Most of this 26 percent not found can be attributed to the delay between the time of flagging (generally September or October 2011) and that of surveying (summer 2012). Some of the data from the spreadsheet, including descriptions of the high-water marks and elevations, also are displayed on a clickable map in appendix 3.

Summary

Vermont experienced two historic flood events in 2011. The wettest spring on record in Burlington (19.94 inches of precipitation from March through May) resulted in a new record for stage (103.27 feet on May 6, referenced to the National Geodetic Vertical Datum of 1929) at the Lake Champlain at Burlington, Vermont, gaging station (04294500). The water level in Lake Champlain remained above National Weather Service flood stage of 100 feet for 68 days between April 13 and June 18. Presidential declarations of major disasters were made in June, July, and November 2011 as the result of the severe storms and flooding during April through June 2011 around Lake Champlain.

From August 28–29, 2011, record rainfall from tropical storm Irene (3 to more than 7 inches statewide) caused extensive flooding throughout Vermont on a scale not experienced since 1927. Eighty-eight percent of municipalities in the State suffered damage. New record streamflows were recorded at nine sites in and near Vermont and nine other sites had peak streamflows among the top four of record. A fourth presidential declaration of disaster was made in Vermont following tropical storm Irene, which (with subsequent amendments)

Figure 4. High-water marks associated with flooding from tropical storm Irene in August 2011 in Vermont. These photographs represent typical manifestations of high-water marks and are ordered generally from best to poorest quality: *A*, mud line on a building; *B*, debris line on a fence; *C*, silt line on a tree; and *D*, wash line on the ground.

authorized individual assistance for 12 counties, public assistance for all 14 counties, and hazard mitigation statewide.

High-water marks (HWMs) from the spring and August floods in Vermont were flagged by the U.S. Geological Survey (USGS) during the 2011 field season. The highest levels of Lake Champlain from the May 2011 flood peak were documented with 39 HWMs in four counties. These HWMs generally were identified and flagged at lake access areas and boat launches.

Flood levels of Vermont rivers after tropical storm Irene were documented with 1,138 HWMs in 12 counties. These HWMs generally were identified and flagged upstream and downstream from all structures in stream reaches that were heavily impacted by flooding. A system of protocols for identifying and recording HWM information using personal digital assistant devices equipped with a global positioning system was developed to ensure consistent data collection among field crews. The success rate for finding flagged HWMs by the contracted survey crews was 74 percent. The surveyors produced a spreadsheet with surveyed horizontal coordinates and vertical elevations and a report describing methods and metadata. In the next phase of this project, survey data from these flood elevations will be used by the USGS to generate flood inundation maps for selected study reaches in Vermont.

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Appendix 1. Report prepared by Dewberry to document the Vermont high-water mark survey, September 19, 2012.

[Available separately at http://pubs.usgs.gov/ds/763/]

Appendix 2. Elevations of high-water marks from flooding in Lake Champlain from April through June 2011 and tropical storm Irene, August 28–29, 2011, in Vermont.

[Available separately at http://pubs.usgs.gov/ds/763/]

Appendix 3. Map of high-water marks from flooding in Lake Champlain from April through June 2011 and tropical storm Irene, August 28–29, 2011, in Vermont.

[Available separately at http://pubs.usgs.gov/ds/763/]

Prepared by the Pembroke Publishing Service Center.

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