Lake Champlain Basin Program

Flood Resilience in the Lake Champlain Basin and Upper Richelieu River

2013

Learning from the Past, Preparing for the Future

A comprehensive review of the 2011 flooding impacts on a watershed level to inform flood resilience policies and management strategies in the Lake Champlain Basin

The Flood Resilience in the Lake Champlain Basin and Upper Richelieu River report was produced by the Lake Champlain Basin Program (LCBP) in partnership with the New England Interstate Water Pollution Control Commission (NEIWPCC).

Lead Author: Stephanie S. Castle.
Contributing authors: Eric A. Howe, Emily L. Bird, William G. Howland.
Graphic Design: Elizabeth Lee Newman and Ryan Mitchell.

LCBP thanks U. S. Senator Patrick Leahy for identifying financial support for this task.

LCBP wishes to thank the many individuals who assisted in the preparation of this report, whether by providing data, images, pictures, or advice, or by acting as reviewers. In particular, we acknowledge the staff of the Vermont Agency of Natural Resources, Québec Ministère du Développement durable, de l'Environnement, de la Faune et des Parcs, and the New York Department of Environmental Conservation.

Suggested citation: Lake Champlain Basin Program 2013. Flood Resilience in the Lake Champlain Basin and Upper Richelieu River.

Cover: Spring Lake flooding, showing sediment discharge into Lake Champlain. Photo: LCBP

Development and production of this report was funded by an agreement awarded by the Great Lakes Fishery Commission (GLFC) to the New England Interstate Water Pollution Control Commission (NEIWPCC) in partnership with the Lake Champlain Basin Program (LCBP). NEIWPCC manages LCBP's personnel, contract, grant, and budget tasks and provides input on the program's activities through a partnership with the LCBP Steering Committee.

NEIWPCC

Lake Champlain Basin Program

Table of Contents

Executive Summary

The flood events of 2011 left a profound and lasting impact on the watersheds of Lake Champlain and the Richelieu River Valley and their residents. Lake Champlain reached flood stage on April 13, 2011 and remained above this level for 67 days until June 19, 2011. A new record was set on May 6, 2011, when Lake Champlain crested at 103.27 feet above mean sea level.

High water levels severely impacted the shoreline of the Lake, inundating houses and other lakeshore structures at low elevations, eroding vast amounts of shoreline that had not previously been exposed to wave action. The Richelieu River, Lake Champlain's outlet, was also greatly affected by the high water levels, and several communities along the River were severely impacted by flooding for the two-month duration of the spring 2011 events. A few short months later, Tropical Storm Irene arrived in the region on August 28, 2011, bringing significant rainfall to the southern segments of the Champlain Basin and causing severe flash flooding of tributaries in this area, impacting thousands of people in Vermont and New York.

The Lake Champlain Basin Program (LCBP) was commissioned by Governor Shumlin of Vermont and Premier Charest of Québec to coordinate a conference to address the spring 2011 flooding of Lake Champlain and the Richelieu River Valley. The impacts of Tropical Storm Irene were subsequently added to this request. The LCBP hosted workshops in Saint-Jean-sur-Richelieu, Québec and Plattsburgh, New York to discuss specific topics associated with the Lake and tributary flooding.

A two-day conference was then held in June 2012 in Burlington, Vermont to continue discussion of ideas proposed in these workshops and to discuss topics such as climate change impacts to the region, impacts to the lakeshore and tributaries from flooding, emergency response, transportation and other infrastructure, and agriculture.

The second day focused on policy perspectives to move forward in the Basin. This report provides a summary of these 2011 events — the impacts to humans, to our infrastructure, and to the ecosystem in which we live — and a series of policy recommendations for the three jurisdictions of the Champlain Basin (New York, Québec and Vermont) to consider for increasing resilience to future flood events in the region and beyond.

Many of these recommendations are derived from the fundamental issue of identification and protection of existing floodplains (Lake or tributary) and restoration of these critical areas, where feasible, that have been compromised by human development. In turn, protection of floodplains will reduce the volume of water delivered to Lake Champlain, attenuating the Lake elevation. Consequently, many of these recommendations serve the dual purpose of protecting life and property along tributary corridors, including the Richelieu River, as well as along the shoreline of Lake Champlain.

A list of 15 policy recommendations is provided below, with a brief description. Please refer to the full text, provided on page 75 of this report, for a complete description of these concepts.

- **Identify and promote economic benefits for improved flood resilience**
  ➢ A thorough economic review of the impacts of Lake and tributary flooding to the region's economy should be provided to provide justification for implementing flood resilience policies and programs.

- **Develop a comprehensive hydrological model for Lake Champlain, including flood frequency and severity analyses for flood hazard mapping**
  ➢ Jurisdictions should regularly update flood frequency data and projections, incorporating predicted changes in weather patterns due to climate change.
  ➢ Develop a model to predict water movement throughout the Lake Champlain and Richelieu River watersheds, incorporating predicted weather patterns.

- **Identify Fluvial Erosion Hazard (FEH) areas**
  ➢ Identification of FEH areas is critical to predicting the most susceptible locations for the next flood event, and implementation of BMPs to reduce these risks.

- **Establish floodplain development standards**
  ➢ Floodplain development guidelines should reduce or restrict development in and near these critical zones.

- **Establish lakeshore protection zones**
  ➢ Reduction or restrictions of "hard" structures such as seawalls along the lakeshore in lieu of natural vegetated shoreline zones.

- **Reduce bank armoring of the tributary network and lakeshores**
  ➢ Armoring of tributary banks and lakeshores should be reduced to the most sensitive areas to protect existing infrastructure.

- **Promote community acceptance of floodplain management principles and regulations**
  ➢ State and Provincial regulating agencies should work with local governing bodies to help them understand flood resilience principles to improve compliance.

- **Implement flood resilience tax reductions for lakeshore and riparian properties**
  ➢ Tax codes can be modified to provide incentives for landowners of lakeshore and riparian lands to develop and implement appropriate conservation practices and Flood Resilience Plans.

- **Establish monitoring sites to document changes in ecosystem resilience**
  ➢ Long-term monitoring sites should be identified to document changes in reference and impaired conditions for flora and fauna of the Champlain ecosystem pre- and post-flood events.

- **Develop Risk Management Plans for wastewater treatment facilities, public water supplies, and hazardous waste sites and identify funding mechanisms to implement the plans**
  ➢ Critical water infrastructure sites (WWTFs, water suppliers) and hazardous waste sites located in floodplains should have Risk Management Strategies or Plans to reduce susceptibility to flood events.

- **Update design standards for transportation infrastructure**
  ➢ Design standards for roads, culverts, and bridges need to reflect changing climate conditions and intensity of precipitation events. Dams should be assessed for decommissioning potential to restore floodplain connectivity.

- **Work with communities to develop or improve emergency response plans**
  ➢ Emergency Response Plans should be developed at the State or Provincial and local levels to expedite emergency relief efforts during future flood disasters.

- **Develop flood-resilience compensation programs from insurance and mortgage lenders**
  ➢ Insurance providers and mortgage lenders working should consider risks assumed for structures located in flood hazard zones and adjust eligibility and rates to reflect this risk.

- **Develop flood resilience guidelines for the agricultural community**
  ➢ Producers should develop flood resilience plans for their farms and implement practices to increase storage of floodwaters.

- **Development of a flood resilience coordinator position or office**
  ➢ Coordination of flood resilience efforts within the jurisdictions, including development of training programs, education and outreach programs, and flood resilience efforts among federal, state or provincial, and local governance programs.

An example of post-Irene river repair work in the Boquet River, NY. Photo: Boquet River Association

Introduction

This report discusses the short- and long-term impacts of the 2011 floods on different aspects of the Lake Champlain watershed, including ecological, agricultural, infrastructure, and developed and undeveloped lands. To mitigate future flood impacts, the existing flood response framework is evaluated at municipal, state, and national levels. The report will identify information gaps and opportunities for improvement by examining existing emergency response, management strategies, and policy. Finally, we will recommend action steps to help jurisdictions within the Lake Champlain Basin better prepare for future flood events.

History of Flooding in the Lake Champlain Basin & Upper Richelieu River

The Lake Champlain Basin boasts access to valuable natural resources and navigable waters and highly productive agricultural lands. These qualities have provided an attractive place for humans to live for a thousand years. This close connection to the land and its tributaries has led to widespread development throughout the Basin. Given the topography and climate of the area—steep mountains with narrow valleys, high snow yields and humid summers—the Basin has a unique hydrology that is especially prone to flooding. There have been several large scale flooding events affecting both the Lake and its tributaries since continuous record-keeping began in the early 20th century.

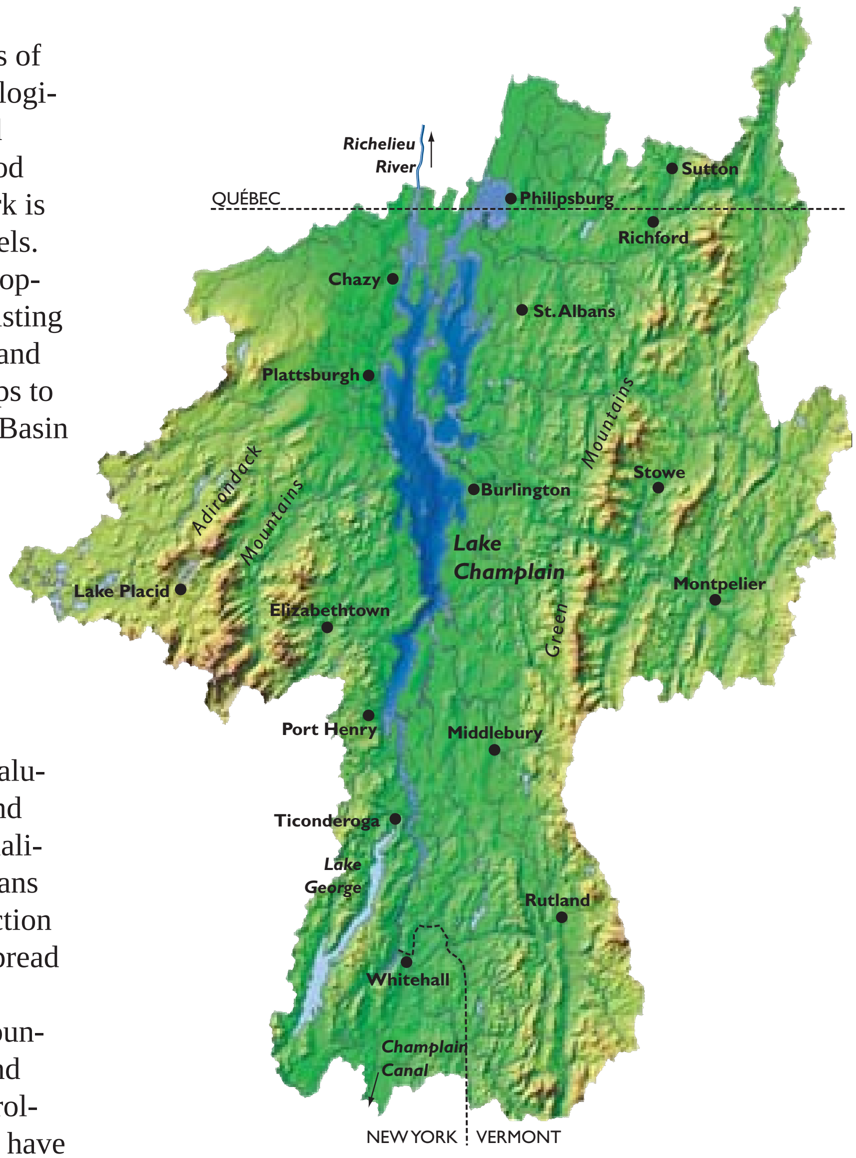


Figure 1. Lake Champlain Basin Map

In 1927, a late-season hurricane struck the Basin, causing the most destructive tributary flooding ever recorded. There were successive spring floods through the 1930s caused by high snowmelt runoff from the mountains. In 1936 and 1938, fall hurricanes caused significant tributary flooding in all jurisdictions of the Basin and in the Richelieu River. During the 1970s, there were again several large snowmelt events coupled with rainy spring storms that led to Lake flooding and that damaged many properties along the Richelieu River. A stepped 1.5-foot (0.45 m) increase occurred in the average yearly Lake levels in the 1970s that has been sustained ever since.[1] High-volume winter storms caused more spring flooding in 1993 and 1998, and Lake levels reached a new high of 101.9 ft (31 m) in May of 1993.[2] A very snowy winter and wet spring in 2011 caused record-breaking Lake flooding that severely impacted shoreline areas throughout the Champlain and Richelieu River valleys. In August 2011, Tropical Storm Irene led to extensive tributary flooding through most of southern and central Vermont and parts of eastern New York, breaking records and causing loss of life and extensive property damage. Some 25 disastrous regional flood events have affected both the Lake and tributaries of the Lake Champlain Basin and the upper Richelieu River from 1997–2011.

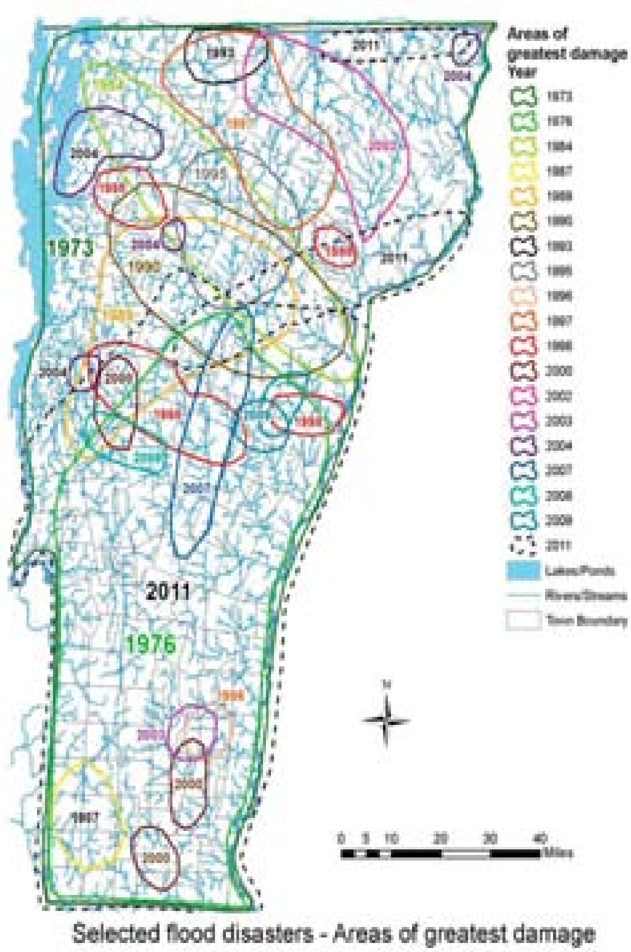
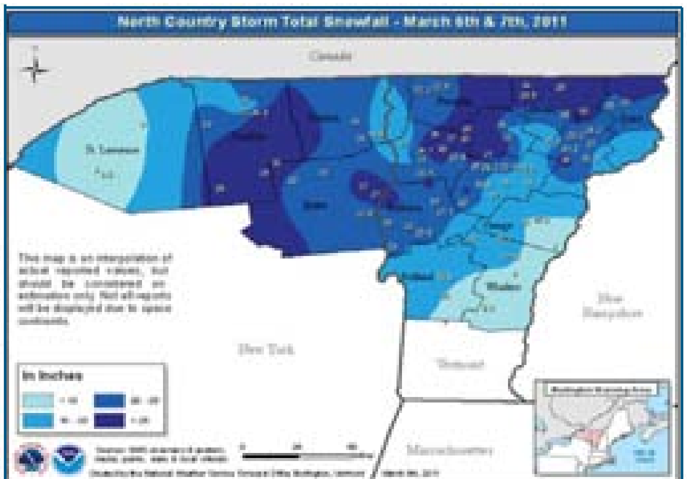


Figure 2. Areas of major flood damage from prior flood events illustrating the history of flooding in the region. Courtesy: VT ANR

2011 Lake and Tributary Records

In the Champlain Basin, the intensity and prominence of the 2011 floods was unprecedented. In May of 2011, record snowfall followed by snowmelt combined with heavy spring rains flooded the level of Lake Champlain to record high of 103.27 feet (31.47 m) above mean sea level (AMSL), 1.25 ft (0.4 m) above the previous record, increasing the Lake's surface area by 66 square miles (106.2 km^2).[3] Major damage from the spring Lake flooding was primarily from long periods of inundation coupled with intense wave-action causing remarkable shoreline damage, along with fluvial damage in tributaries.

A few months later in August of 2011, Tropical Storm Irene reached Vermont and New York, producing 11 inches (28 cm) of rain within 24 hours, and strong winds in many areas. Damage from Tropical Storm Irene was characterized by extensive streambank erosion as a result of flash flooding and record stream flow in Lake Champlain's tributaries and other major watersheds of Vermont and parts of New York. The intensity, prominence, and resulting destruction of the 2011 floods were an alarming call to action. 2011 was the only year on record in which the Basin faced both record spring flooding and extensive fall hurricane tributary damage due to flash flooding.



Snowfall from a single winter storm in the Lake Champlain Basin, March 6-7, 2011.
Courtesy NOAA/NWS

Lake Champlain Basin Region August 27-28, 2011.
Courtesy NOAA/NWS

Figure 3. Regional winter snowfall accumulations, spring rains and Irene total rainfall.
Courtesy: NOAA/NWS.

Adaptation to Climate Change

Climate change is a long-term shift in weather patterns and atmospheric energy. Depending on geographic location and topography, climate change may cause record-breaking storms and unfamiliar episodes of flood and drought. In the case of the Lake Champlain Basin and upper Richelieu drainage system, climatologists believe increased annual precipitation and flooding will continue to be a consequence of climate change. A study by the National Oceanic and Atmospheric Administration (NOAA) found in the Northeast region of the U.S. 76% of stream gauges show an increase in flood magnitude in recent years and 80% of stream gauges show increases in flood frequency suggesting the continuation of flood events in the future.[4] Scientists predict more hurricanes to take a northerly route through New England as surface temperatures of the Atlantic Ocean continue to rise. Tropical Storm Irene made landfall in northern New Jersey, an increasingly common occurrence.

Long-term monitoring of weather in the Basin measured an average air temperature increase of 2.2° F (1.2° C) since 1976,[5] and Lake Champlain surface water temperature has increased 6.8° F (3.8° C) since 1964.[6] An average increase of three inches (7.6 cm) in annual precipitation has occurred over the past 40 years.[7]

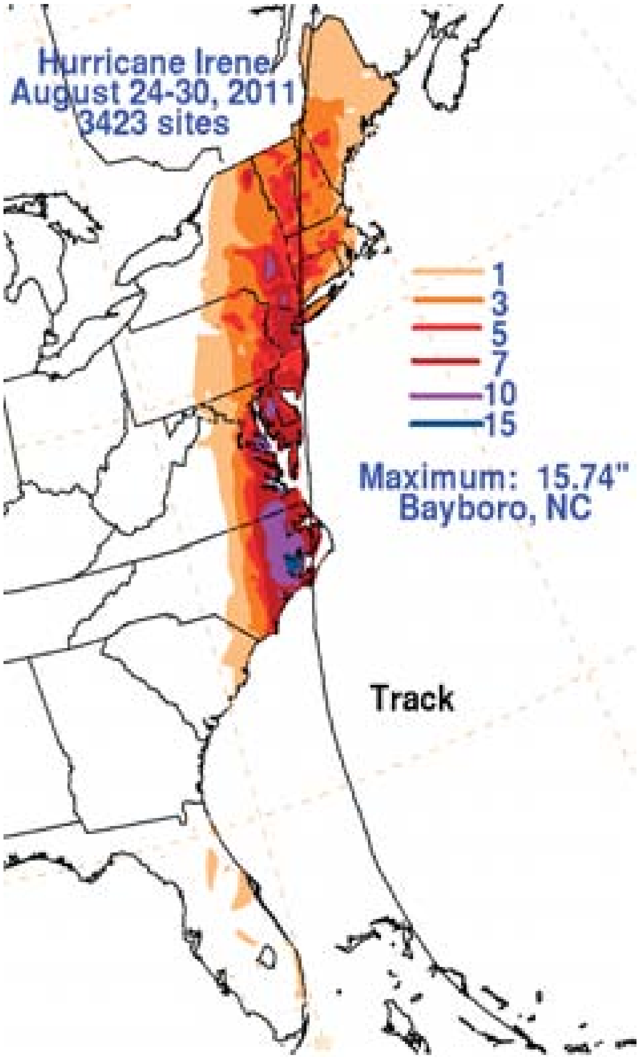
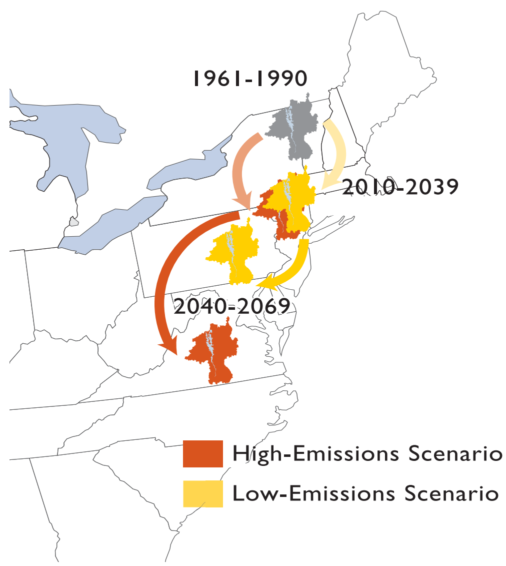


Figure 4. Tropical Storm Irene projected path, August 24-30, 2011. Courtesy: NOAA/NWS

Collectively, these changes have resulted in a measurable shift in regional climate. According to a National Weather Service gauge, Lake Champlain has completely frozen over fewer times in the past 50 years than it did, on average, in the prior 130 years.[8] As climate indicators, these are dramatic increases that inarguably show that the climate of the Lake Champlain Basin is changing. On a global scale, reducing emissions of greenhouse gasses (particularly carbon dioxide, methane, nitrous oxide, etc.) could curb the extent of climate change, but such reductions are not sufficiently occurring. At a watershed level, decision-makers must focus on adaptation: making ecosystems, developed land, and rural areas more resilient to environmental, economic and human impacts of continuing climate change and expected increases in the frequency and severity of storm events and the associated floods.



Red arrows track the shift in the Lake Champlain Basin's summer climate over the next 60 years if we continue under a high-emissions scenario. Yellow arrows track the shift under a low-emissions scenario.

DATA SOURCE: Adapted from Union of Concerned Scientists.

Figure 5. Migrating Climate

Endnotes

1. USGS/NOAA Lake Champlain Gage at Burlington, VT (http://waterdata.usgs.gov/vt/nwis/uv?site_no=04294500); Mike Winslow, staff scientist at Lake Champlain Committee presentation entitled “Lake Flooding: We’ve Been Here Before” at LCBP Flood Resilience Conference June, 2012.

2. USGS/NOAA Lake Champlain Gage at Burlington, VT (http://waterdata.usgs.gov/vt/nwis/uv?site_no=04294500).

3. USGS Inundation Map & USGS/NOAA Lake Champlain Gage (http://waterdata.usgs.gov/vt/nwis/uv?site_no=04294500).

4. Douglas, E. M. and C. Fairbank, 2011. Is precipitation in New England becoming more extreme? J. Hydrologic Engineering, 16 (3):203-217; Spierre S and CP Wake, 2010. Trends in Extreme Precipitation for the Northeast United States, 1948-2007. Carbon Solutions New England Report and Clean Air-Cool Planet Report.

5. Stager, C. and M. Thill. 2010. Climate Change in the Lake Champlain Basin: What natural resource managers can expect and do. Keene Valley, NY and Montpelier, VT: The Nature Conservancy.

6. Smeltzer, E., Shambaugh, A., Stangel, P. 2012. Environmental change in Lake Champlain revealed by long-term monitoring. Journal of Great Lakes Research, 38, Supplement 1, pp. 6-18.

7. Stager, C. and M. Thill. 2010. Climate Change in the Lake Champlain Basin: What natural resource managers can expect and do. Keene Valley, NY and Montpelier, VT: The Nature Conservancy.

8. USGS/NOAA Lake Champlain Gage at Burlington, VT (http://waterdata.usgs.gov/vt/nwis/uv?site_no=04294500).

Impact on Ecosystems & Undeveloped Land

Water Quality and Water Levels

Data from a number of Lake level gauges maintained on Lake Champlain, show that over the past 50 years, the annual mean water level in the Lake has increased by 1.5 feet (0.45 m). During the spring 2011 flooding, Lake Champlain rose to 103.2 feet (31.4 m) above mean sea level (AMSL), a 1.3 foot (0.4 m) increase from the previous record set in May of 1993.[9] Even with excellent short-term weather forecasting, there was no way to predict how quickly or for how long the Lake level would rise and remain above the 100 ft (30.5 m) flood stage; the Lake remained above this level for more than two months. With the impact of wind generated wave action, the effective elevation of Lake Champlain during the spring of 2011 was over 106 ft (32.3 m) at times.

Lake Champlain was elevated for several weeks with occasional strong winds blowing from the South that produced high flows in the Richelieu River Valley. Rates of more than 45,900 ft^3/s or cfs (1,300 m^3/s) near Saint-Jean-sur-Richelieu were observed from late April 2011 to early June 2011. The two highest flows observed were 54,880 cfs (1,554 m^3/s) on May 6, 2011 and 55,090 cfs (1,560 m^3/s) on May 23, 2011.

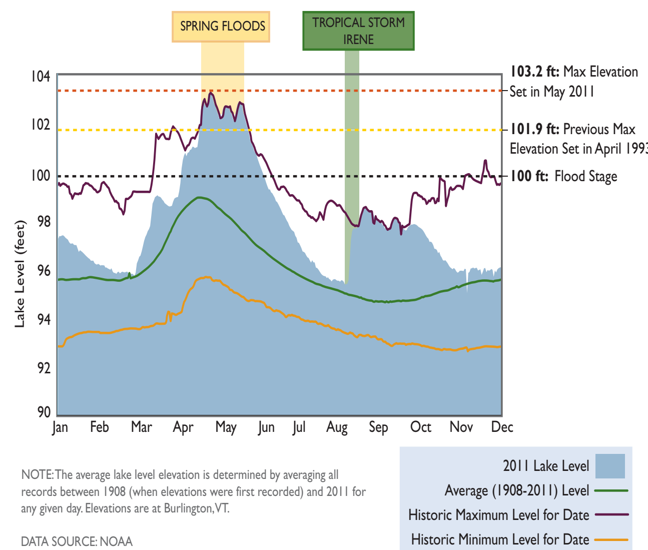


Figure 6. Lake Champlain level during 2011 with major flood events highlighted. Previous maximum, mean and lows for each date are also shown, along with the flood stage. Data courtesy: NOAA/USGS

During Tropical Storm Irene, historic water levels were exceeded in five Basin rivers. In-stream gauges allowed some early warnings for downstream municipalities, sparing lives and informing evacuation efforts. The discharge from tributary flooding into the Lake caused a rapid 3-foot (1 m) rise in Lake elevation.[10]

Flooding Impacts

Water quality is almost always negatively affected by intense flooding, and that was clearly demonstrated by the spring 2011 Lake flooding. A result of combined snowmelt runoff and heavy spring rains, flood waters flowed through the tributary network into the Lake over the course of several months. High snowmelt runoff increases hillslope erosion, while high tributary discharge leads to stream bank erosion and bottom scouring. Nutrients such as phosphorus and pollutants, including kerosene and pesticides, may be adsorbed to the surface of sediment particles and transported to the Lake with them in turbid water. Documented short term impacts on water quality from the 2011 flooding included: higher stream and Lake turbidity, increased nutrient load, locally elevated bacteria levels, and elevated soluble chemical load. All of these factors have impacts on aquatic life and the potential to cause harm to humans through drinking, direct contact and use of contaminated water. Due to the likelihood of chemical and pathogenic contaminants carried by the floodwater, "*do not drink*" water advisories were issued for areas with submerged wells. Québec residents were provided supplies of drinking water by the Provincial government due to the long duration over which water supplies were at risk. An estimated 20,000 people were affected by compromised drinking water supplies. Floodwaters running through municipalities mobilized hundreds of gallons of household chemicals, impaired septic systems, and diluted spilled fuels. In the first week after Tropical Storm Irene, 14 times the usual number of hazardous waste and fuel spills was reported. During the spring flooding, over 20 sewage overflows were reported in the Basin.[11] After Irene, some 10 wastewater treatment facilities in the Basin reported compromised operations, although most problems were short-lived and plants returned to full operations within a week of the storm. Vermont estimated that 10 million gallons of raw or untreated sewage was discharged into waterways statewide as a result of Irene.[12]

The potential long-term consequences of the 2011 flood events on water quality are not fully known. The influx of sediment and nutrients lowered Lake water clarity and enhanced the conditions that promote algal blooms. In 2011, phosphorus concentrations in nearly all Lake segments were higher on average, than during any other year of record. Recent calculations of phosphorus loading in tributaries show levels 1.7-2.8 times the average levels. Scientists are still determining the impacts on water quality due to the high nutrient loads of 2011. If higher nutrient levels persist, more frequent cyanobacteria (blue green algae) blooms may occur in the future. Several beach closures occurred during 2012 as a result of cyanobacteria (blue-green algae) blooms, particularly in Missisquoi Bay, reducing the recreational use of the Lake in that area.

Shoreline erosion in the record high waters of the spring Lake floods impacted many areas of well-developed shoreline soils that had never previously been subjected to wave action, due to their elevation. These eroded soils included organic material that was redistributed in the near-shore littoral areas, where it remains. Organic material decomposition in the near-shore areas will result in decreased dissolved oxygen near the Lake bottom, increasing the likelihood that legacy phosphorus stored in sediments will be released into the water. This increased dissolved phosphorus will be available to support blue-green algae blooms in many areas until the organic materials have decomposed. Recovery times for complex systems like the Lake Champlain Basin are often very long, likely involving many years, in the case of the 2011 floods.

Existing Management

During flood events, the top priority of emergency response at every level is to protect human life and property. The effects of flooding on water quality, both short- and long-term, have an impact on the human quality of life and the economic drivers that benefit from Lake Champlain. The immediate emergency response to the floods was almost entirely related to preserving human health and economic or infrastructure resources. Public drinking water supplies are monitored by state agencies and standards for training, emergency preparedness and multiple levels of disinfection are in place should a flood occur. During the spring 2011 flooding, jurisdictions issued safe drinking water advisories and supplied bottled water to flood victims. Low-impact flooding, in which the floodwaters did not cause substantial structural harm, still required evacuations due to the inflow of water likely contaminated with sewage, chemicals and other pollutants.

Contamination also delayed on-the-ground response efforts in some areas, and required personal protective measures for recovery workers.[13] Immediate clean-up efforts focused on stopping sewage overflow and containing hazardous waste, accruing costs over $1.75 million[14] in Vermont alone. All crops inundated by floodwaters from Irene were deemed unfit for human consumption by the FDA, due to possible contamination, and had to be destroyed or demonstrate that the risks from flood waters contamination could be mitigated. Most produce grown for human consumption was discarded at an estimated loss of over $10 million.[15]

The spectrum of long term mitigation strategies is broad and vigilance is needed to ensure proper installation of private septic tanks and hazardous material storage tanks. All U.S. wastewater treatment facilities are subject to specific state and federal guidelines that require adequate performance in flooding scenarios. These standards are re-examined after every major flood event to ensure future preparedness. In Québec, provincial guidelines for wastewater treatment facilities address flood risks categorically. Facility operators are routinely trained for emergency response.

Many ongoing efforts to reduce the input of excess sediment and nutrients to waterways also helped to minimize impacts on water quality during the 2011 flood events. Best Management Practices intended to improve river corridor management have improved stream access to floodplains, and urban planning and development has in recent years been alert to the problems of urban stormwater. Agricultural Best Management Practices (BMPs) reduce soil erosion and may improve crop yields, and also reduce the negative effects of rural storm water on water quality.

Water quality may always be negatively affected by extreme events, but better waste management, community planning, and farm practices to achieve improved flood resiliency are an important approach to reduction of flood impacts.

Management Needs

- Build or retrofit existing wastewater treatment facilities to be more flood-resilient, including Combined Sewer Overflows, hazardous waste sites and drinking water supplies to prevent future flood damage
- Create a comprehensive hydrological model that predicts the impacts of future flooding events on drinking water supplies, wastewater treatment facilities and water quality
- Create and maintain a publicly accessible Basin-wide flood forecasting system

Information Gaps & Data Needs

Information Gap: What are the impacts of increased flood events on wastewater facilities and drinking water supplies?

Data Needed:

- Documented impacts of floods on wastewater and hazardous material facilities that will inform a management strategy to prevent damage from future floods and preserve drinking water supplies.
- Emergency spill response plans for every municipality that should be updated annually
- Strategic plans for potable water supplies during major flood events
- Consistent, long-term data sets of Basin-wide water quality before and after major flooding events, including sediment levels, water clarity, dissolved oxygen and toxin levels
- Models showing runoff from fields and urban landscapes to help predict nutrient and pollutant levels in surface water runoff post-flood
- Map of sediment plumes in the Lake through publicly available aerial imagery

Lakeshore property in North Hero, VT. Photo: LCBP

Biodiversity & Aquatic Invasive Species

The impacts of the 2011 flood events on the biodiversity of the Lake Champlain Basin and upper Richelieu River are not fully known. Lake and river ecosystems are known to be very resilient with respect to natural fluctuations, even in extreme conditions. The Lake Champlain Basin contains more than 300,000 acres (121, 405 hectares) of wetlands and includes 91 species of fish, 312 species of birds, 56 species of mammals, 21 species of amphibians, and 20 of reptiles. The Lake ecosystem is directly connected with the Richelieu River and a wide array of organisms. The 2011 flood events affected each part of the Lake Champlain ecosystem differently. These parts will be discussed individually, as shorelines and wetlands, aquatic environments, terrestrial environments, and invasive species.

Flooding Impacts

Shorelines and Wetlands: High Lake levels, coupled with gusty winds caused substantial shoreline erosion, property loss, fallen trees and loss of vegetation.[16] Floating debris injured tree stems and exposed roots near shorelines. Standing water during the sustained spring Lake flood killed many near-shore trees and drowned wetlands.
As the floodwaters receded, extensive sediment deposition, potentially containing toxins and contaminants, was left behind in wetland and coastal areas. These sediments buried native vegetation and stationary fauna, such as mussels. There was a slight landward movement of coastal flora and fauna. As water flooded shoreline environments, fish moved out of the water column and became trapped outside of their natural environment when waters receded. In Québec, scientists rescued nearly 1,000 stranded fish in farm fields following the spring flood.[17]

During Irene, streams laterally eroded with the floodwaters, washing riparian vegetation downstream, and changing the configuration of the streambed and the structure of the adjacent floodplains.[18]

The flooding events of 2011 significantly impacted the morphological and vegetative structure of coastal areas, which could have a long-term impact on the existing riparian flora and fauna. Sediment deposited along shorelines and in wetlands will remain in place indefinitely, potentially affecting the long-term survivability of benthic biota. Nesting birds may have abandoned flooded nests during the spring flood, but will most likely return in the coming years.

Aquatic Environments: During the extended spring Lake flood, the littoral zone was considerably expanded, providing access to more habitats for spawning fish. However, cool Lake water temperatures delayed spawning times. Fry emergence in whitefish and lake trout was delayed by two weeks in the spring of 2011.[19] In Vermont, state fish biologists studied wild trout populations in the Mad and Dog River watersheds both before and after Irene-related flooding. Wild trout populations in studied streams were reduced to 33-58% of pre-Irene levels. Benthic invertebrate populations dropped nearly 95% after Irene.[20] The State Roxbury Fish Hatchery suffered damages costing $500,000 when Irene flooded its facilities. Toxins and pesticides carried by floodwaters into several streams and lakes, may impact the reproductive success and productivity of phytoplankton and macroinvertebrates,[21] though some research has shown diluted levels due to high water volume.

Tropical Storm Irene also impacted aquatic biota, including fish and aquatic insects (invertebrates). In Québec, scientists have noticed large populations of tench that were not observed prior to the Lake flooding.

Highly fecund fishes, such as tench (*Tinca tinca*), may have benefitted from the increased access to spawning habitat provided by the spring 2011 flood events. While data are not available specific to the Richelieu River valley, tench populations do appear to have increased in the St. Lawrence River as a result of the 2011 flooding. Conversely, some fish spawning areas may have been compromised during the flooding. Primary spawning areas for the endangered copper redhorse (*Moxostoma hubbsi*) were impacted to changes in flow patterns and substrate in the Richelieu River at Chambly, which could reduce spawning success of this species in this segment of the River.

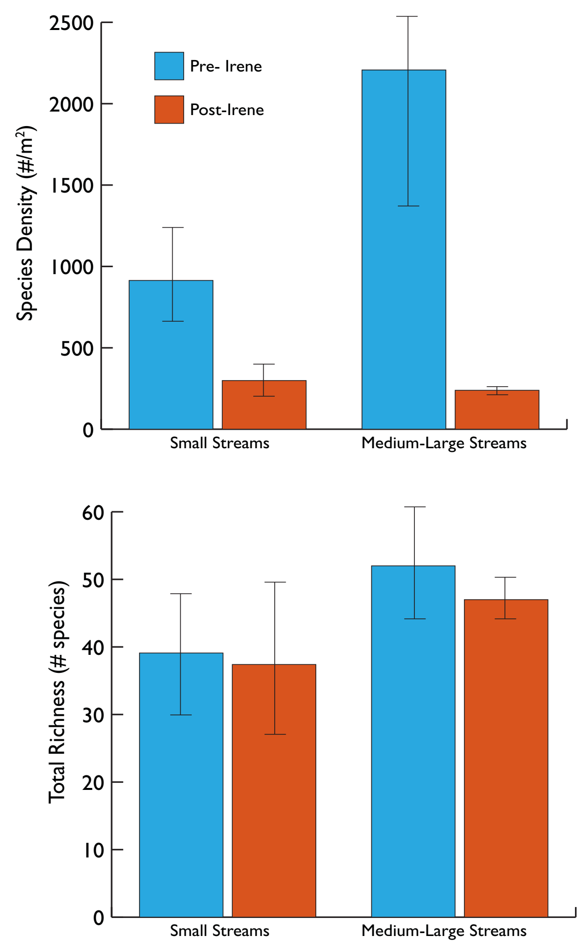


Figure 7. Species density and richness pre- and post-Irene in small and medium sized streams in Vermont. Data courtesy: VT ANR

In other flood-affected areas in the region, aquatic species population rebounds have occurred within 2-4 years after the flooding. It is likely that fish and invertebrate populations that dropped following the 2011 floods will return to their approximate pre-flood levels within 5-10 years.[22] With enhanced nutrient loading from tributary flooding and shoreline erosion, the Lake is at risk for increased blue-green algal blooms, which may impact the entire aquatic ecosystem and lead to decreased biodiversity and lower benthic oxygen levels and increased mobilization of nutrients in legacy sediments. During extensive blue-green algal blooms toxic conditions may develop.

In streams affected by post-Irene channel remediation or streambed gravel extraction and tree removal, benthic flora and fauna and fish populations may be affected over a period of years depending on the extent of disruption. Fish populations can take a long time to recover in poorly managed, homogeneous tributary systems that lack diverse habitats, flows and depths necessary for success.[23]

Terrestrial Environments: High water levels impacted habitat for low-nesting birds and delayed the nesting season for some species. Sight-oriented predators, such as osprey, were disadvantaged due to increased turbidity in the Lake during the prolonged spring flooding. After Irene, in which wind gusts reached over 50 mph (80.5 km/h), aerial surveys found over 9,000 acres (3,642 hectares) of woodland with downed trees and impacted vegetation cover in Vermont.[24]

Loss of forest crown canopy cover impacts forest floor ecosystem dynamics for many years. The destruction of many trees by the storms of 2011 may have resulted in decreased habitat for nesting birds and tree-dwelling creatures. Increased sunlight on disturbed forest floors creates opportunities for fast-growing invasive species whereas a healthy forest community may be more successful in competitive exclusion of invasive species. High levels of accumulated sediment and debris in some streamside forests has led to the establishment of invasive plants which may compete successfully with forest species over time. Recreation in Vermont State Forest lands was adversely affected due to long-term closures of roads, trails and bridges following Tropical Storm Irene.[25]

Invasive Species: Aquatic invasive species may have expanded their local range due to the increased access to habitat afforded by high water levels, but these invasions have not yet been observed. No new invasive species are yet known to have been introduced to Lake Champlain as a known result of the 2011 floods. Potential colonization by invasive species of impaired areas may occur quickly after a flood event. Non-native species such as Japanese Knotweed *(Fallopia japonica)* may transform the character of the forest floor, roadside, or other disturbed area within weeks. No new invasive species have been documented in the Lake Champlain Basin as a direct result of the flooding. However, the degree to which invasive species have spread along damaged riparian zones and other impaired areas, is yet to be determined. Some sea lamprey *(Petromyzon marinus)* traps were destroyed or buried by sediment; it is believed sea lamprey did not extend further into the watershed as a result of the 2011 floods. An impact on delta spawning habitat from increased sediment is likely but its extent is unknown.[26] A delayed start to the growing season allowed potential riparian invasive species to colonize before native plants could be established in disturbed ground. Highly impacted areas are still recovering and it is not yet known to what extent invasives may out-compete native plants immediately after the flooding.

Existing Management

Habitat Conservation

Resources management agencies constantly struggle to balance sustainable development within natural ecosystems. Preserving riparian zones, protecting existing healthy habitats and restoration of degraded habitats are methods of reducing the impact of flooding on ecosystems and to humans. Healthy systems rebound from environmental impacts of flooding faster than degraded systems. Keeping riparian habitat contiguous and minimizing fragmentation facilitates the movement of populations in the event of a flood. Conservation of upland habitats will have a positive impact on the wetlands and lakes receiving runoff from upland sources. Knowledge of the likely impacts of flooding on the natural environment can inform management strategies and hazard planning. Mapping of affected areas and periodic surveys of indicator populations will improve understanding of the impacts of flooding on habitat and species diversity.

Prevention of the Spread of Invasive Species

Increasing education and awareness of the threat of invasive species has been shown to have a positive impact on invasive species management and new species arrivals. Rapid response and management for elimination of any new invasive species is an essential practice to maintain the integrity of existing ecosystems, both aquatic and terrestrial.

Venise-en-Québec Jamson Park, May 6, 2011
Photo: QC MDDEFP

Management Needs

- Ecosystem-wide strategy to preserve healthy ecosystems and enhance habitat connectivity. Included in this strategy would be detailed mapping in reference and impaired sites of habitat and a baseline catalogue of selected flora and fauna.

- Protocol to contain the spread of invasive species post-flood events

Information Gaps & Data Needs

Information Gap: What are the impacts of floods on Lake Champlain on ecosystem health and biodiversity?

Data Needed:
- Long term data sets and mapping of flora, fauna and habitat in riparian zones and comparison to pre- and post-flood events to inform modeling of flood impacts on species diversity, population patterns and ecosystem health
- Understanding of the impact of toxins and pollutants on Basin flora and fauna

Information Gap: To what degree do floods facilitate the spread of some invasive species?

Data Needed:
- Surveys of invasive species distribution pre- and post-flood
- Invasion Risk maps to predict downstream invasion probabilities to help target post-flood invasive species management

Morphology (Erosion & Deposition)

Flooding Impacts

In the spring of 2011, the level of Lake Champlain rose over a foot above the previous recorded maximum to 103.27 ft (31.47 m) and remained above flood stage for more than a month.[27] The spring flooding primarily impacted shoreland through erosion driven by strong winds and large waves. Wave action resulted in shoreline erosion up to five ft (1.5 m) above the record high Lake level. Eroded shorelines led to property destruction, habitat loss, fallen trees and increased sediment and organic material deposition along the shore. Sediment eroded from the shorelines contributed to lower water clarity in Lake Champlain. Some sections of lakeshore were minimally affected by erosion, while other areas were greatly impacted. Most of the erosion occurred in areas where the largest waves broke onshore, in the lee of long zones of uninterrupted fetch - in which wave development was greatest. Other than the exposure to fetch and storm winds, the character of the shoreline was the greatest determinant of erosive damage. Shorelines with poor management, such as steep banks with little vegetation and lawns extending to the water's edge or shoreline immediately adjacent to seawalls were especially vulnerable to erosion. Bridges and causeways across the Lake suffered significant damage during the prolonged spring flooding, mostly because of their unusual exposure to high winds and strong waves.

Short-term impacts following Irene included substantial stream channel erosion and changes in valley morphology. High stream discharges led to bank collapse, gullying, downed trees, and movement of large boulders and coarse material. In some places, rivers changed course following Irene affecting the entire structure of the river corridor.

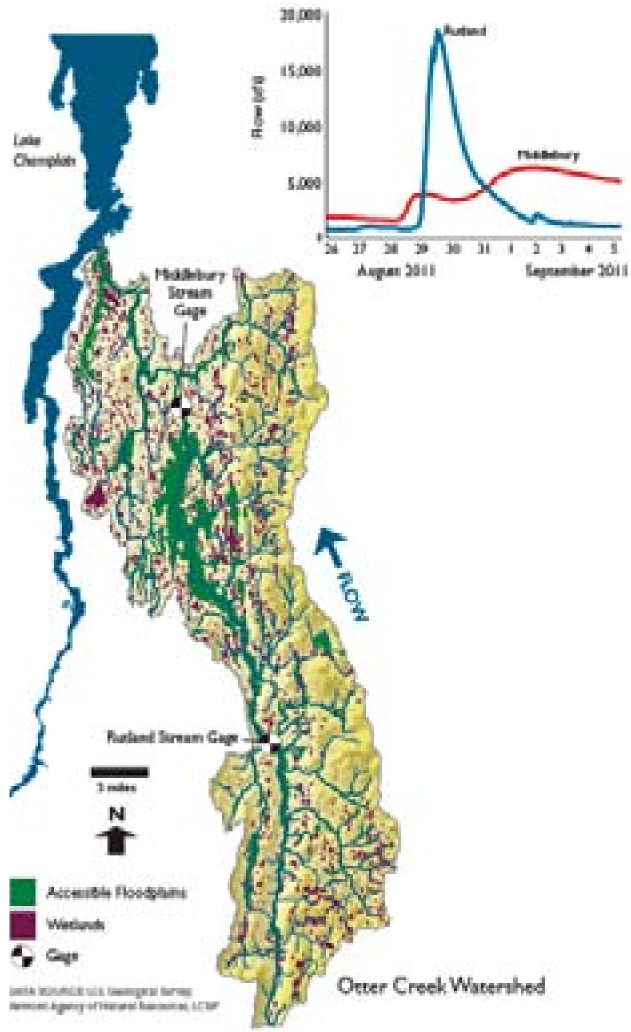


Figure 8. Otter Creek, Vermont during Tropical Storm Irene, illustrating the impact of floodplain availability on peak discharge. Allowing floodplain access significantly decreased river flow downstream. Data courtesy: USGS

Eroded material, sometimes carrying pathogens, chemicals or nutrients, was washed downstream into Lake Champlain. Irene led to record or near-record discharges in many Basin tributaries.

The short-term effects of Irene on Lake levels resulted in a moderate but rapid increase to record levels for the latter part of August, but did not approach the Lake levels normally associated with spring floods. The Richelieu River stage remained well below flood level in the period during and following Tropical Storm Irene.

The long-term morphological impacts of 2011 Lake floods have not been fully tabulated as of December, 2012. Eroded shorelines may remain in their new configuration for many years. In places where homeowners have rebuilt pre-existing shoreline following erosion, future storms may well again cause extensive erosion.

The effects of increased sediment deposition into Lake Champlain, its tributaries, and the Richelieu River are not yet known. Streambank erosion from Irene caused long-term changes in river form in many areas. In Vermont, reconstruction of streams in a few critical areas was overseen by river management specialists, and intended to accommodate future flooding events. Damage to structures and infrastructure along stream courses was widespread as flooding streams reclaimed access to floodplains, and in many cases, existing infrastructure influenced the morphological adjustments that resulted (for examples, railbeds and armored roadsides).

Existing Management

River Corridor and Shoreline Management

Comprehensive river corridor and shoreline management programs and strategies are developing in Vermont, New York and under research in Québec. Federal programs in the United States address floodplain management using both structural and non-structural measures, including:

- Floodplain Delineation/Flood Hazard Evaluation
- Dam Breach Analysis
- Flood Warning Preparedness
- Floodway Regulation
- Flood Damage Reduction/Urbanization Impact
- Flood Proofing of Infrastructure
- Inventory of Flood Prone Areas[28]

These programs allow for federal funding through the U.S. Army Corps of Engineers to match state or municipal funding for flood resilience studies. The goals of these programs are to reduce the vulnerability of both the natural and the built environments to flood and erosion hazards and to create ecologically sound rivers and lakes in view of increasing human development. Close interaction with water systems has always been a part of life in the Lake Champlain Basin and upper Richelieu River. For centuries, streams large and small have been channelized, re-routed, dredged or regulated. Even today, management of these resources from place to place focuses on preserving economic investments, recreation, power generation, water quality and supply. Increasingly, management practices include approaches to avoid further encroachment in river corridors and on floodplains and shorelines. Finding ways to minimize new development in these riparian areas is an essential part of resource management for flood resilience that will mitigate existing hazards, and increase ecosystem stability at the same time.

The floods of 2011 occurred in two phases. The spring Lake flood was a sustained record high increase in water levels affecting lakeshore communities, while Irene was a short-term flash flood event mostly impacting communities in the watershed rather than along the Lake. Forecasting of the water levels of the spring event was helpful in important ways, but did not fully anticipate the impact of wind and wave action on shorelines. A general forecasting system in Québec predicted the extent of flooding along the Richelieu River. Flood forecasting in Vermont and New York, through the efforts of NOAA and USGS, were essential to alerting residents in each jurisdiction of the nature and general extent of the pending flood. The eventual record Lake water levels were not predicted until just before they occurred.

The forecasts of precipitation and flooding from Tropical Storm Irene were very widely broadcast, although the location of most intense impact could not be predicted effectively. It is easy to forget the floods of 1927 and the hurricane of 1938 struck the region without warning.

Assessment of the impacts of the 2011 flood events has led to an increased commitment to insightful management strategies that aim to promote system resiliency, a return to (or preservation of) natural river processes that redirect floodwaters onto adjacent floodplains, and attenuate both the flows and erosive energy of floodwaters in the river channels. There is renewed focus on effective stream management, extending the boundaries of management to include not only the channel and immediate floodplain, but also the entire river valley. Efforts to improve shoreline management call for a better understanding of wind and wave action on exposed shores. Across the board, there is a need for more advanced spatial data and analytic tools to better inform runoff models. In each jurisdiction, there is renewed interest in stream corridor restoration and protection to improve outdated management regimes and to promote resilience.[29]

Floodplain Development

The topography of the Lake Champlain Basin is diverse, including steep mountains, narrow river valleys and broad floodplains. Communities close to rivers are particularly prone to flood damage. But the ease of the development of transportation corridors reflects the history of the rivers themselves as corridors, and has led to an abundance of building in floodplains in both the Lake Champlain Basin and the upper Richelieu River valley. In many cases, towns and public infrastructure built next to streams and lakes have been affected by multiple flood events over the years. Floodplain management measures aim to protect life and property and are carried out on the local, state or provincial and federal levels. Most U.S. municipalities participate in the National Flood Insurance Program (NFIP) as a means of qualifying for flood insurance within the federally mapped flood hazard areas, though participation is not mandatory. The NFIP relies on decades-old topographic and stream discharge data, and flood hazard maps are almost uniformly outdated. Updated flood hazard maps should be improved using high resolution topographic data (such as LiDAR). New maps should also include data for climate change and flood frequency analyses to create a comprehensive view of current and future flood hazards. What was understood to be a 100-year flood a few decades ago was the basis of a flood hazard map zone that maybe inaccurate given current weather patterns and precipitation trends. We may expect a new calculation of the 100-year flood for any area would result in a higher water level, and also would encompass a greater spatial area of hazard on the floodplain maps. In most updated maps, FEMA's designated Base Flood Elevation (BFE) has been raised to accommodate changing 100-year flood elevations.[30] Currently the BFE for Lake Champlain is 102 ft (31 m) AMSL. In New York, all new construction must have the lowest floor two feet (0.6 m) above this elevation.[31]

In nearly all cases, damaged roads and bridges in Vermont and New York were more impacted by erosion than by the inundation hazards conveyed by the NFIP maps and FEMA hazard mitigation programs.

Act 110 (passed in May of 2010) in Vermont gave communities the authority to mitigate their own flood hazards, and sought to provide financial incentives for towns to limit development in river corridors and lake shorelands through zoning restrictions in order to reduce property loss and damage from erosion.

The Government of Québec adopted the *Politique de protection des rives, du littoral et des plaines inondables* (see Québec Floodplain Policies in Appendix B) in December of 1987 with the following objectives:

- To ensure the sustainability of bodies of water and watercourses, and to maintain and improve their quality by ensuring adequate, minimum protection of lakeshores, riverbanks, littoral zones and floodplains;
- To prevent the degradation and erosion of lakeshores, riverbanks, littoral zones and floodplains by encouraging their preservation in their natural state;
- To preserve and maintain the quality and biodiversity of the environment by limiting activities which may give greater accessibility to and permit the development of lakeshores, riverbanks, littoral zones and floodplains;
- In the case of floodplains, to ensure the safety of persons and the protection of property;
- To protect plants and wildlife characteristic of floodplains by taking into account the biological characteristics of that environment, and to ensure the natural streamflow is not impeded;
- To promote the rehabilitation of degraded riparian zones using the most natural techniques possible.

Before the floodwaters receded from the 2011 Lake flooding, the Québec provincial government provided significant support as a direct assistance payment to property owners impacted by floodwaters of the Richelieu River. In this policy structure, the Province self-insures for flood damage to citizens. There are extensive regulatory criteria for development in floodplains in Québec, although pre-existing development is generally accommodated, and eligibility for compensation for flood damages is subject to compliance. After the floodwaters receded, the provincial government enacted a floodplain development strategy entitled the 2011 Richelieu River Flood Special Planning Zone in response to concerns from local municipal officers (see Québec Declaration of a special planning zone Appendix B).

- In the 0-2 year flood elevation, reconstruction is prohibited.
- In the 0-20 year flood elevation, any new construction is prohibited.
- In the 2-20 year flood elevation, reconstruction of a home destroyed during the 2011 flood is allowed only by the owner, if a year-round occupant at that time.
- Repair or reconstruction must comply with flood-proofing standards.

These new standards of this Special Planning Zone in Richelieu changed the regulation in place since 1987 to allow reconstruction of homes destroyed in the 2-20 year flood elevation. In St-Jean-sur-Richelieu, many blocks within the urban area were flooded and thousands of people had to be evacuated from their homes for a prolonged period. The interest in repairing or rebuilding onsite in the status quo is understandable, though not always in the public interest.

Flood Hazard Management

When the flooding occurred in 2011, many municipalities made decisions about the management of rivers within their jurisdictions. Management efforts during and immediately following the floods focused on preserving lives and property. Much of this emergency work was carried out by municipal employees, contractors, and in some cases by volunteers with equipment and necessary excavating skills. The state and federal governments also carried out emergency management on streams and lakeshores to stabilize banks and protect essential infrastructure.

In the days following Tropical Storm Irene, a number of management actions in river channels resulted in continuing or even greater instability, and increased the risk of downstream flooding in future storms.[32] The State of Vermont has estimated that only 20% of the recovery activities in affected streams following Tropical Storm Irene helped to reduce the level of vulnerability than existed before the storm hit. Another 40% likely made the channels more vulnerable than they were prior to flooding. In the spring of 2012, the Vermont State legislature passed Act 138, which granted the State authority to coordinate all emergency river management activities for flood hazard areas.[33] In Québec, individuals responsible for inappropriate management of shorelines and floodplains after the flooding can be legally obligated to implement corrective measures.[34] The Québec MDDEFP was closely involved with ensuring that proper management techniques were used during the corrective process following the 2011 Lake flood. In New York, FEMA contracts for post-flood management currently includes funds for NFIP public outreach workshops with local code enforcement staff. However, these workshops are not frequent enough to train all potential municipal officials.[35]

Management Needs

Management Need: Identify fluvial erosion hazard areas (i.e., river corridors) and manage these areas to prevent damage from future floods:

- Gully and Erosion Control
- Buffer Establishment and Protection
- Removal of Structural Encroachments
- River and Floodplain Restoration:
    - Protection of river corridors and floodplains
    - Stabilize stream banks where stream equilibrium conditions have been achieved
    - Arrest head cuts and knick points
    - Remove berms and other constraints to flood and sediment load attenuation
    - Remove/replace structures (e.g. undersized culverts, low dams)
    - Restore incised and aggraded reaches

Management Need: Re-examine flood frequency data to inform updated Flood Hazard zones

- Update flood return intervals to ensure 100-year flood zone, per federal flood insurance maps, are accurate with respect to changing climate conditions and recent data

Management Need: Regulatory tools are needed to limit the extent to which development activities encroach upon or change the physical integrity of floodplains, and the easy connection of rivers with their floodplains.

- Enhance State and municipal floodplain regulation and floodplain protection outreach programs.

- Purchase easements to protect the remaining undeveloped floodplains

- Create tools and incentives for community-based river corridor protection strategies

- Encourage communities to establish a higher level of regulation for flood damaged structures to be replaced or repaired to reduce future flood damages and losses

- Provide training for engineers and contractors on typical and non-typical designs for flood-prone buildings

Management Need: Establish technical standards and rules for conducting in-stream work and emergency protective measures.

- Enhance and integrate state-level emergency operations with the operations of other agencies, nonprofits, municipalities and the federal government, and within Québec. Continue to support the integration of efforts among involved ministries and municipalities to ensure collaboration in management response to flooding.

- Establish or maintain a River Management training program for transportation staff, contractors and other river professionals.

- Re-evaluate emergency management plans

- Complete Local Flood Hazard Analysis to model river hydrology and create designs for attenuating flood energy and flows in a community to support the coordination of river corridor planning with commerce, community development, and transportation planning.

Information Gaps & Data Needs

Information Gap: Re-examine the calculated return interval for significant floods, such as a 20- or 100-year flood, to ensure that the associated flood hazard maps are updated and accurate.

Information Gap: Comprehensive river corridor planning with hydraulic modeling to predict the vulnerability of community assets and inform specific local mitigation strategies that are ready to implement in the aftermath of a future flood when financial and technical resources are made available.

Data Needed:
- Historical stream and Lake gauge data; continuation of funding for the USGS gauging program
- Updated NFIP maps with up-to-date 100- and 500-year base flood elevations
- Develop maps of flooded area in and around the Lake during the extended snowmelt floods of May 2011 from satellite imagery
- Develop Basin-wide hydraulic model
- Compare flood extent from remote sensing with DEM elevations and field observations. (It may be necessary for jurisdictions to acquire contemporary LiDAR terrain elevation data for both of these hazard identification programs.)
- Develop stage-lake area ratings for Lake Champlain

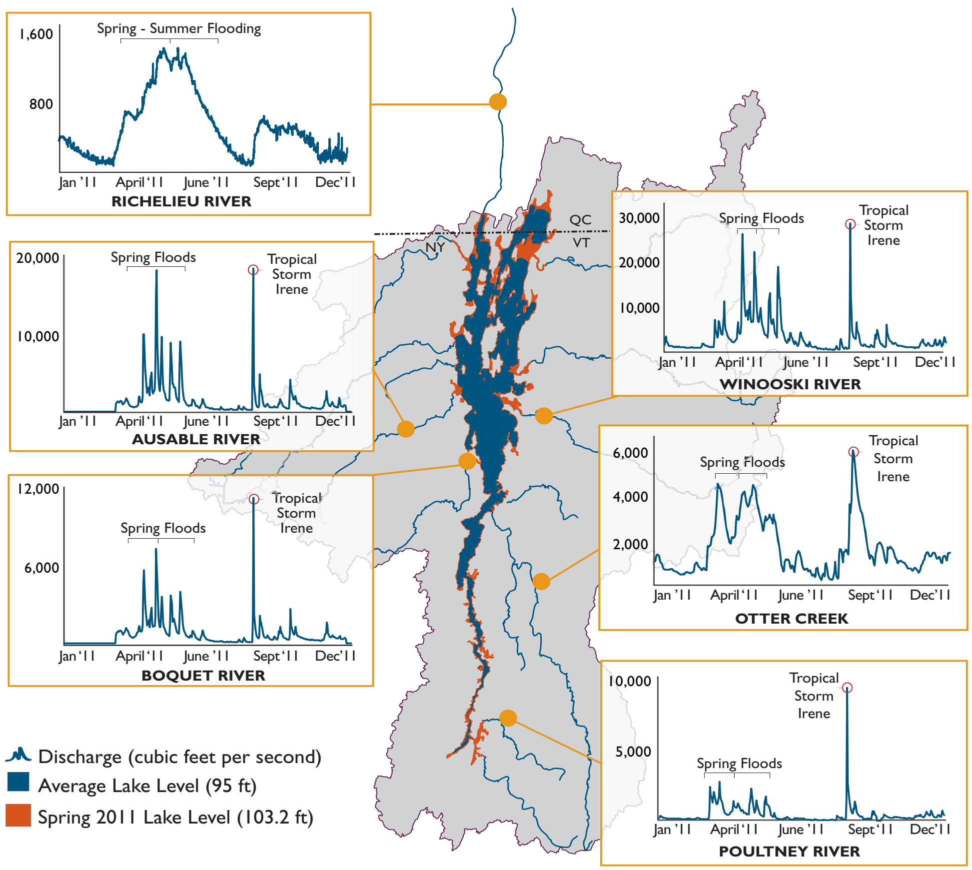


Figure 9. Flooding of 2011 in the Lake Champlain Basin. The spring Lake flooding is shown in orange and tributary flow peaks are shown on the blue graphs. There are several peaks during periods of heavy rain in the spring, and another peak after Tropical Storm Irene. Data courtesy: USGS

- Map and assess full extent of flooding around the Lake using publicly available remote sensing data. Publicly available (free) remote sensing sources used include:
  - Landsat 5 and Landsat 7 – 30 m resolution, 7 band color, approximate weekly repeat cycle depending on cloud cover
  - MODIS - 250 m resolution, 2 band carried on the TERRA and AQUA satellites, capable of seeing the Lake one to two times each day depending on clouds.
  - SPOT 4 and 5 – 10 m resolution, color infrared, can observe Lake depending on clouds, approximate weekly repeat cycle depending on clouds, not generally available free of charge.
  - Satellite Altimetry – Jason 2 (OSTM) 10 day repeat cycle, and ENVISAT 35 day repeat cycle. The radar altimeters are not limited by clouds. Vertical accuracy is dependent on ground and atmospheric conditions, on the order of 10 cm
  - CHPS: Community Hydrologic Prediction System- hosted by NOAA

Endnotes

9. USGS/NOAA Lake Champlain Gage at Burlington, VT (http://waterdata.usgs.gov/vt/nwis/uv?site_no=04294500).

10. USGS/NOAA Lake Champlain Gage at Burlington, VT (http://waterdata.usgs.gov/vt/nwis/uv?site_no=04294500).

11. VT ANR Wastewater Management Division (http://www.anr.state.vt.us/dec/ww/om/Overflows/ReportedSewageOverflows.pdf).

12. VT ANR Wastewater Management Division (http://www.anr.state.vt.us/dec/ww/om/Overflows/ReportedSewageOverflows.pdf).

13. VT ANR Irene Report, December 2011, http://www.anr.state.vt.us/anr/climatechange/irenebythenumbers.html.

14. VT ANR Irene Report, December 2011, http://www.anr.state.vt.us/anr/climatechange/irenebythenumbers.html.

15. Neale Lunderville, Vermont Irene Recovery Report, January 2012 (http://www.vermontagriculture.com/news/2011/Irene_Recovery_Report_Jan_2012.pdf).

16. Susan Warren, section chief, Lakes and Ponds Management Program, VT ANR, presentation at LCBP Flood Resilience Conference, June, 2012.

17. Steve Garceau, QC MDDEFP, personal communication, September, 2012.

18. Mike Kline, Program Manager, Rivers Management Program, VT ANR- presentation at LCBP Flood Resilience Conference, June 2012.

19. Dr. Ellen Marsden, University of Vermont, personal communication, October 2012.

20. Rich Kirn, VT FWD 2011 2011 Annual Report: Impacts to Stream Habitat and Wild Trout Populations in Vermont Following Tropical Storm Irene (Proj. No. F-36-R-14). Covering the period of July 2, 2011-June 30,2012. 17pp.

21. Toxic Substance Management Strategy: Managing Toxic Contamination of Lake Champlain. Technical Report #69 Lake Champlain Basin Program Technical Advisory Committee, 2012, 28 p.

22. Rich Kirn, VT FWD 2011 Annual Report: Impacts to Stream Habitat and Wild Trout Populations in Vermont Following Tropical Storm Irene (Proj. No. F-36-R-14). Covering the period of July 2, 2011-June 30,2012. 17pp.

23. Rich Kirn, VT FWD 2011 2011 Annual Report: Impacts to Stream Habitat and Wild Trout Populations in Vermont Following Tropical Storm Irene (Proj. No. F-36-R-14). Covering the period of July 2, 2011-June 30,2012. 17pp.

24. Sandy Wilmot, Forest Health Specialist. "2011 Flooding Summary for Forests, Parks and Recreation. Vermont Department of Forests, Parks and Recreation, 2011.

25. Sandy Wilmot, Forest Health Specialist. "2011 Flooding Summary for Forests, Parks and Recreation. Vermont Department of Forests, Parks and Recreation, 2011.

26. USFWS (http://www.fws.gov/lcfwro/index.html). Accessed June 2011

27. USGS/NOAA Lake Champlain Gage at Burlington, VT (http://waterdata.usgs.gov/vt/nwis/uv?site_no=04294500).

28. Gene Brickman, USACE, personal communication, December 2012.

29. NYS DEC (http://www.dec.ny.gov/lands/311.html) & VT ANR (http://www.anr.state.vt.us/dec/waterq/rivers/htm/rv_restoration.html.

30. FEMA.gov/ Rebecca Pfeiffer, Floodplain Manager, Assistant NFIP Coordinator, VT ANR, personal communication December 2012.

31. Fred Dunlap, Lake Champlain Coordinator, NYS DEC, personal communication, December 2012.

32. Mike Kline, Program Manager, Rivers Management Program, VT ANR- presentation at LCBP Flood Resilience Conference, June 2012.

33. Vermont Legislation Act 138 (http://www.leg.state.vt.us/docs/2012/Acts/ACT138.pdf), November, 2012.

34. Martin Mimeault, Lake Champlain Coordinator, Québec MDDEFP, personal communication.

35. Fred Dunlap, Lake Champlain Coordinator, NYS DEC, personal communication, December 2012.

Impact on Infrastructure & Developed Lands

Human Health

Extended duration of flood events can have significant impacts to human health. Private residences and public infrastructure inundated with water contaminated by toxins and toxic substances during the 2011 Lake flood event and post-Tropical Storm Irene were severely damaged and in many cases needed to be razed. Floodwaters were a source of physical, toxicological and microbiological hazards, posing a significant threat to human health. After the waters receded, mold and mildew growth became a serious concern for property that had been inundated.

No deaths were directly attributed to the spring 2011 Lake Champlain flooding, although there were substantial immediate impacts to lakeshore residents and residents of the Richelieu Valley caused by the long-term inundation of residences. Over 25 municipalities were affected in the Richelieu Valley and 40 municipalities in Montérégie by the spring Lake flooding in Québec, including nearly 3,000 permanent residences. Of these, 3,927 people were directly affected, among which 1,651 had to be evacuated from their homes.[36] Tropical Storm Irene was responsible for four deaths in the Lake Champlain Basin — two in Altona, New York and two in Rutland, Vermont.

Deaths attributed region-wide to Irene were caused by wash-outs, downed power lines, and the duties of public workers and emergency response.

In Québec, the eight-week period of inundation presented home owners with water damage, environmental health issues including mold exposure and electrical hazards. For the first few weeks, 1,600 residents were displaced from 2,400 homes.[37] To accommodate evacuees, the Canadian Red Cross set up emergency shelters. Some families moved into hotels with assistance from the Provincial government, Canadian Red Cross and SOS Richelieu. Approximately 540 families utilized the Canadian Red Cross service and as of early June 2012 nearly 150 families remained in hotels.[38, 39] Volunteers were a major workforce in the Québec flooding. SOS Richelieu, a community group, worked with Québec Civil Protection to facilitate a 4,000 participant volunteer event to assist in clean-up efforts. Additionally, MDDEFP provided inspectors for environmental health and hazardous waste. Twenty different communities were affected by the flooding, costing over $70 million to support flood victims by the Government of Québec.

Flooding Impacts

Emergency Response

Immediate needs following the spring flooding and Tropical Storm Irene were to supply clean drinking water, contain spills of toxic substances, provide medical care, and to repair damage to transportation infrastructure to gain access to communities isolated by washed out roads.

During flood events, the first action is to ensure human safety. Evacuation—voluntary, recommended, or mandatory—was an emergency response measure used throughout New York, Vermont, and Québec during both flooding events of 2011. Evacuations occurred in high-risk areas where people were isolated with medical needs, exposed to structural damage, environmental health hazards, or electrical hazards. Many voluntary evacuations occurred where families with children or elderly relatives took precautionary measures to eliminate risk and discomfort. Flood victims were supported in various ways by community, state or provincial, federal and non-government organizations who rapidly established programs to support flood victims.

Power Outages

Power outages presented additional hazards, limiting ability for people to heat their homes or to boil water. For high-risk individuals, loss of power meant spoilage of certain medicines. For example, diabetics were at higher risk without a viable insulin supply. During the spring floods, Québec residents relied heavily on their government to supply food and medicine throughout the prolonged flooding. State-wide in Vermont, 73,000 customers were without power (40,150 restored after 24 hours and the rest of the customers restored after a week).[40] Nearly 945,000 customers in New York were without power after Irene, 177,000 of those in upstate New York including counties of the Lake Champlain Basin.[41]

Additionally, utilities were forced to shut down power in areas where flooding could cause further electrical hazards. People using generators to power their homes risked carbon monoxide intoxication if operated in badly ventilated areas.

Pathogen and Contamination Exposure

Risk of exposure to pathogenic microorganisms in the Basin's public water resources was increased due to compromised public water systems and private wells, septic systems and sewers, and the failure of wastewater treatment systems. These failures led to widespread environmental health hazards during both the spring flooding and Irene events. Private wells submerged in flood waters were at risk of contamination by bacteria and other pollutants. Broken pipes reduced water pressure in public water systems, increasing the likelihood of contamination.[42] Flood waters can mix with sewage containing human waste and contaminate well water, public water supplies, and food sources. Public health officers recommended to residents using well water in flooded areas to boil water prior to use until laboratories certified the water as potable. Additionally, wet conditions promoted the growth of mold and mildew, impacting respiratory health, particularly for those with asthma or weakened immune systems. Mold growth often occurs within 48 hours of receding flood waters. Once mold is present in a building, it is difficult to properly eliminate. Inhalation of mold spores into the airways is a common cause of respiratory irritation, allergic reaction, asthma attacks, chronic sinusitis and other conditions. Some molds are potentially toxic and can have serious health effects. On the short-term, mold removal of fabric, furniture, drywall material and all other surfaces where mold growth is susceptible. However, long-term mold growth might persist in building cavities, in walls and other hidden spaces, potentially contaminating the structure on the long-term. Inactive mold spores remain viable and can disperse, potentially causing chronic health problems post-flood.

Molds are problematic as there is no exposure threshold limit and there are difficulties when it comes to precisely assessing the associated risk of mold exposure. There is limited guidance for mold control, including mold management and risk evaluation. There is also a need to improve communication and collaboration with built environment experts to reduce risk of mold in new construction or renovation projects of flood-inundated properties.

There were also risks of infection when handling soiled wet material and when soaking in contaminated water to clean. Skin infections from cuts or sores in contact with contaminated water can be serious. The Public Health Agency of Montérégie has produced a number of recommendations addressing disaster, including precautions for the use of drinking water, disinfection of houses and mold prevention. The agency also provided disaster workers, volunteers and increased availability of vaccination against tetanus.[43]

Aside from the relocation of people during flooding events in 2011, the greatest impacts on the built environment in Québec was removal and disposal of soaked and contaminated material and the rebuilding process. The reconstruction lasted months for some, and more than a year for others. Frequently, houses that were not structurally damaged were inhabitable because of mold infestations.

The long-term human health impact of the 2011 floods is difficult to evaluate. However, nutrient and chemical contamination from the floods undoubtedly contributed to human health issues. Flood waters carried household chemicals from garages and basements; propane gas and oil tanks were damaged or disconnected from homes, leaking into the environment. Hazardous chemicals introduced into the Lake by floodwaters added to the existing contaminants in the Lake, potentially contaminating drinking water supplies, fish and other aquatic organisms. High nutrient levels in the Lake, as observed following both flooding events, promote cyanobacteria (blue-green algae) blooms. If ingested, cyanotoxins released by cyanobacteria can affect humans and animals. While many scientists speculate that harmful algal blooms and toxin contamination may be amplified by the 2011 floods, a direct link between the two events has not been confirmed.

Flood Waters & Public Drinking Water Supply

Prevention of exposure to contaminants is the highest priority of emergency management of drinking water supplies. The Vermont Department of Environmental Conservation (VT DEC) is the regulatory entity for drinking water supplies in Vermont. The VT Department of Health (VT DOH) establishes the framework for the municipalities to issue boil water advisories during power outages, flooding, and water treatment infrastructure damage.[44] During the spring 2011 Lake flooding, VT DOH issued boil-water advisories for thousands of shoreline homes who rely on private wells for water supplies. During Tropical Storm Irene, 30 public water systems issued boil water advisories affecting 16,590 people statewide.[45]

In New York, the Department of Health (NYS DOH) provides a framework for public water suppliers to issue boil water notices. In an emergency, the supplier must report any risk to human health to the local Department of Health.[46]

Port Henry, Essex, and Willsboro issued boil water notices, affecting about 3,600 residents during the spring flooding.[47] Portions of Essex and Clinton counties also were under a boil water notice following the Tropical Storm Irene event.

The Québec Department of Sustainable Development, Environment, Wildlife and Parks (MDDEFP) provides guidance to municipal drinking water suppliers including response protocols if risk of contamination occurs. Local water suppliers report potential human health hazards back to Québec MDDEFP.[48] During the spring 2011 Lake flood, none of the major suppliers were impacted, but many facilities had to increase chlorination and filtration because of increased turbidity. Washouts caused by Tropical Storm Irene affected three public drinking water supplies (about 50,316 people) in Québec.[49]

Monitoring for E. coli and cyanobacteria (Blue-green algae) Toxins

Flood events typically increase contaminants to the Lake, including E. *coli* and other pathogens. As a public safety measure, coliform bacteria monitoring occurs at public beaches and in public water supplies on a weekly basis, or more frequently during periods of elevated bacteria levels, which can be caused by high streamflows. Cyanobacteria (blue-green algae) blooms also can limit recreational use of the Lake, and occasionally public water supplies if the blooms are severe enough. The Lake Champlain Cyanobacteria Monitoring Program is coordinated by VT DEC in partnership with the LCBP, the Lake Champlain Committee, UVM, and VT DOH to facilitate a cyanobacteria monitoring program to report potentially harmful algal blooms and to sample for cyanotoxins. Reducing phosphorus levels in the Lake would limit the growth of potentially toxic cyanobacteria. Flood resilience measures will help to reduce delivery of sediment and phosphorus to the Lake. Also, increasing flood resilience of existing waste water treatment infrastructure will reduce the chances of releasing these pathogens and other contaminants into the Lake and its tributaries during natural disasters.

Psychological Support

In Québec, the long-lasting flooding triggered intense psychological issues. However, there is no standard protocol in Québec for managing large-scale mental health issues in the event of a disaster and therefore it was not declared a public health issue. According to the needs of victims, psychosocial services were offered in the disaster service centers, with temporary financial assistance from the Department of Civil Protection. Temporary accommodation was offered in local community service centers (CLSC). Psychosocial assistance to individuals, families or groups was offered after the flooding. Response and recovery were conducted by telephone receptions and informational events. More individuals sought out assistance through private care, but statistics are not available for private treatments.

Floods in Montérégie raised a huge wave of sympathy for the thousands of people affected and fatigued by weeks of struggle and stress. Citizens of the Montérégie expressed the need for community support. Their message was heard and the number of volunteers who responded to the appeal exceeded all expectations.

Thousands of volunteers came to the Clean-Up operation on June 11, 12 and 18, 2011 to help victims in the flood-damaged Montérégie. The community group SOS Richelieu recruited more than 4,000 volunteers, coordinated the clean up and called it a great success. Among these organizations are Cadets of the Army, the Canadian Red Cross, blue-collar workers of the City of Montreal and St. John Ambulance.

The Organization of the Québec Civil Protection facilitated the coordination of all operations to ensure that resources were used optimally. Volunteers were spread out in different municipalities and their specific tasks were allocated to meet the needs of citizens and affected municipalities.

Unlike the slow moving disaster in spring for Québec, Vermont experienced very fast paced devastation, suddenly destroying homes and loss of two lives during Tropical Storm Irene. Starting Over Strong Vermont (SOS VT) is a free short-term service provided to individuals, groups, and communities impacted by the flooding from Tropical Storm Irene. SOS Vermont conducts community and door-to-door outreach through counseling and psycho-educational services at group meetings. Along with events, SOS Vermont provides educational resources and documents on their website to assist flood victims in the recovery process.

These efforts have been ongoing since Irene and approximately 10,000 contacts had been made between September 2011 and June 2012 by the organization.[50]

In New York, Tropical Storm Irene was equally devastating. Many homes were destroyed and nine people died, including two deaths in the Lake Champlain Basin. The New York State Office of Mental Health created the Project Hope Crisis Counseling Program to assist individuals, families and groups impacted by Tropical Storm Irene floods. Project Hope services include confidential counseling and public education on services offered to Irene victims in many Irene-impacted New York counties, including Clinton and Essex counties in the Lake Champlain Basin.

The program is funded by the Federal Emergency Management Agency and administered by the Center for Mental Health Services.[51] Counselors met with over 160 individuals affected by both flooding events in Clinton and Essex counties. Additionally, nearly 1,000 residents of Clinton and Essex County registered for FEMA individual disaster relief.[52]

Existing Management

Spring Flooding - Québec

There was a major police deployment from the *Sûreté du Québec* during this disaster to maintain a deterrent presence to counter criminal activity and reassure those finding themselves in precarious situations. In total the police responded to 333 calls in the flooded area during the two month-long operation. The *Sûreté* also opened 134 operational cases related to floods including 12 crimes against people, 38 crimes against property and 84 other cases such as drug possession, disturbed mental state, public assistance, alarms, animal cruelty, and accidents.

St Armand Wharf, May 6, 2011 Photo: QC MDDEFP

A constant police presence helped maintain a strong sense of security for the affected population. Police coordinators were deployed in each of the affected municipalities to coordinate among the various stakeholders. This approach was very successful.

From the first days of flooding in Montérégie, the government assisted and supported the affected population. The Québec government has set up a coordination center to coordinate the efforts of all partners with the municipalities, and has implemented various measures to better meet their needs, including:

- Consolidation of operational staff of Public Safety and Emergency Preparedness;
- Bonus rapid financial assistance program;
- Creation of special teams (accommodation, cleaning and reconstruction, redevelopment and economic);
- Establishment of multidisciplinary teams of reintegration;
- Adoption of a government decree aimed at accelerating payments on government assistance.

On May 11, 2011, the Québec Civil Protection announced the implementation of specific funding program to better help people affected by floods in April and May. Given the duration and the impact this may have on the morale of many victims, new benefits were added to the program in order to offer additional support. A maximum of $150,000 was offered to support permanent residence victims.

Spring Flooding - Vermont

As in Québec, in Vermont, people living on the shores of Lake Champlain were forced from their homes throughout the two months of Lake flooding. The first evacuations reported by the Vermont Red Cross were in Chittenden and Lamoille Counties

Spring flooding in Burlington waterfront, Burlington, VT. Photo: LCBP.

due to flash flooding from heavy rainfall and snowmelt. Neighborhoods in the New North End of Burlington near the mouth of the Winooski River were evacuated.

At the crest of the Lake flooding period, May 6th, 2011, the Vermont Chapter of the American Red Cross assisted 75 individuals, provided 100 clean-up and comfort kits and 400 meals, deploying six Red Cross vehicles and 20 volunteers. Communities assisted by Red Cross included St. Johnsbury, Burlington, Beecher Falls, Essex Junction, Colchester, St. Albans, Cambridge, and Jeffersonville. Displaced residents were housed in motels with cost assistance and a temporary Red Cross shelter was opened in St. Albans.[53] The Red Cross assisted communities affected both by the Lake flooding and by the devastating flash flooding that occurred throughout the Basin during the spring of 2011.

A flash flood along the Winooski River on May 26th, 2011 affected the communities of Montpelier and downstream. Red Cross shelters opened in the Barre Auditorium and the National Life Building in Montpelier. Mobile assets including shelter trailers with cots, blankets and supplies along with Disaster Action Team volunteers were gathered from Vermont and New Hampshire. In addition, VT Governor Shumlin deployed 50 National

Guard Troops to assist emergency response crews with the evacuation process. The night of the flash floods, approximately 170 residents were evacuated to shelters and more residents were evacuated the following day with risk of landslides. Within a week, the number of sheltered residents dropped from 170 to 27, some remaining in shelters for nearly two weeks.

Governor Shumlin requested a major disaster declaration from FEMA on June 15, 2011, requesting federal aid to assist with damages incurred between the dates of April 23–May 9, 2011. In the Lake Champlain Basin, nearly 800 residences were impacted, requiring around $5 million in individual assistance. Costs to rebuild damaged infrastructure are estimated at $3.6 million.[54]

Spring Flooding - New York

In New York, severe spring flooding forced many residents into shelters. The American Red Cross of Northeastern New York supported emergency response efforts in the New York portion of the Basin, providing aid to Clinton and Franklin Counties. Temporary shelters were established in Saranac Lake and Ausable Forks, and Plattsburgh. Voluntary evacuations occurred throughout the New York side of the Basin to escape the Lake flooding and risk of tributary flooding from spring storms and runoff from snowmelt, and to avoid the risk of being caught in landslides.

On June 10, 2011, Governor Cuomo requested a federal disaster declaration to assist with damages from heavy spring storms. Clinton, Essex and Warren counties, within the Lake Champlain Basin, were included in the declaration. Public assistance costs for the affected combined three counties were estimated at $9.9 million.[55]

Tropical Storm Irene - Vermont

During Irene, the Vermont Emergency Management Office was flooded in Waterbury and disaster response headquarters had to be relocated. Road damage from Irene left 13 communities in Vermont isolated state wide without any accessible roads in or out of town.[56]

Tropical Storm Irene forced many evacuations. Vermont and New Hampshire Valley Red Cross established a network of 300 shelters for the region. The Red Cross planned the opening of the shelters prior to the storm's arrival, first at Brattleboro Union High School for the safe transfer of senior citizens from a low-lying housing complex. Seven more shelters in Bennington, Springfield, Hartford, Rutland, Barre, St. Johnsbury, and St. Albans were opened shortly after.[57] During Irene, the Red Cross opened a total of 13 shelters throughout Vermont and New Hampshire with 500 people requiring overnight stays, many arriving throughout the night as floodwaters rose. Of those evacuated, 60 were evacuated from Brattleboro, and 350 homes were evacuated downstream from the Marshfield Dam in East Montpelier as a precaution against failure of the dam. After the storm passed, 4 shelters remained open in Brattleboro, Hartford, Barre, and Rutland. In addition, 24 communities were operating their own shelters.[58] For many of the communities independently sheltering residents, the Red Cross was able to meet supply needs, but dangerous roads and weather limited the reach of the Red Cross for some isolated communities. In total, Red Cross distributed approximately 16,000 meals and thousands of bottles of water during and immediately after the Irene event.[59]

As flood relief efforts shifted from emergency response to recovery, the Red Cross provided mobile outreach efforts with food, health services, damage assessment, client assistance, and the distribution of water and bulk items including clean-up and comfort kits which supplied necessary emergency items. More than 600 clean-up kits were distributed by 500 health service providers and 300 disaster relief providers. The Vermont National Guard was deployed on August 29, 2011, assisting communities through the distribution of goods and services. Fourteen American Red Cross Emergency Response Vehicles from across the country delivered materials to over 26 communities for local distribution, especially for communities where dangerous road conditions limited access. Volunteers helped flood victims cope by identifying steps for the recovery process and connecting victims with community, state and federal resources.[60]

Tropical Storm Irene – New York

Flooding and strong winds forced residents to shelters and required emergency response actions throughout the New York-side of the Lake Champlain Basin. Prior to the storm, residents were urged to prepare for the event by stocking up on water, non-perishable food, flashlights, radio, and first aid kits. Residents also were urged to turn off propane gas tanks, increase refrigeration in case of power outages, and to fill their vehicle's gas tank in case of evacuation.

Essex and Clinton Counties and the Town of Jay were all impacted heavily from the Irene event. Residents were evacuated from the banks of the East Branch of the Ausable River in Keene Valley, and a shelter was set up at the Keene Town Hall. Additional evacuations occurred in Keene and Upper Jay. Similar road damage left communities in Keene, NY isolated. The Essex County (NY) public safety radio system was compromised and the Keene Health Center closed due to flood damage. Compromised communication and health systems led to decreased response times to healthcare emergencies.

By September 5th, 2011, Irene relief statewide in New York included 99 shelters with an overnight shelter population of 6,060, 27 mobile feeding facilities with 1,613 Red Cross workers distributing 67,786 meals.[61] The American Red Cross Northeastern New York Region (ARCNENY, including Warren, Washington, Hamilton, Essex, Clinton, and Franklin counties) provided more than 5,000 meals in this timeframe.

ARCNENY offered a four-hour fast-track disaster relief training session to increase the volunteer force for Irene response from Poughkeepsie to Plattsburgh. Over 200 fast-track volunteers were trained and deployed. In addition, ARCNENY deployed 255 local and nation-wide staff. National Guard and Civil Air Patrol also assisted with evacuations and emergency response.[62] New York Governor Cuomo launched a volunteer effort "Labor for your Neighbor" on Labor Day weekend following Irene to assist with local clean-up efforts.

Over 2,000 volunteers facilitated by the National Guard and State Office of Emergency Management assisted at this event.

Management Needs

- Improve emergency flood response planning in the Lake Champlain Basin to decrease the potential impacts on human health
- Improve short-term response and coordination among jurisdictions
- Improve long-term human health recovery coordination among jurisdictions
- Develop a protocol for addressing the mental health impact of disastrous events as a public health issue

Information Gaps & Data Needs

Information Gap: To what extent did the flooding events increase the presence fecal coliform bacteria (or E. *coli*) in our waterways?

Data Needed:

- Monitor fecal coliform (or E. *coli*) levels over time and determine linkages to flooding and other natural disasters.
- Assess long-term strategy for reducing fecal coliform contamination to help Lake Champlain communities become more resilient to contaminants in the water supply system.

Information Gap: Are harmful algal blooms linked to increased nutrient levels from the 2011 floods?

Data Needed:

- Monitor cyanobacteria levels and their toxins and determine if bloom frequency, duration, and toxicity changes after major flooding events.

Information Gap: What are the psychological impacts of flooding and what are the socioeconomic impacts on the Basin?

Data Needed:

- Compile reports of psychological impacts for Vermont, New York, and Québec caused by the flood events of 2011 and other natural disasters for short- and long-term analysis.

Information Gap: How can communities better support emotional health during disaster as a means of building flood resilience?

Data Needed:

- A successful model of managing mental health on a public health level related to disaster relief. The model should be administered at a local-level, and have self-sustaining funding.

Information Gap: Will increased mold have a long lasting impact on human health in the Basin?

Data Needed:

- The total number of health issues reported related to mold. In each jurisdiction of the Basin.
- Identify levels of mold still present in the flooded build environment.

Built Environment

The geography of the Lake Champlain Basin consists of steep mountains and flat, fertile river valleys. As a result, most historic development occurred in floodplains, along river corridors and near shorelines. As the frequency of flood events trend upward, the cost of maintaining the built environment within floodplains and in close proximity to waterways must be carefully weighed.

Lake Champlain Flood, Spring 2011

The spring floods resulted in widespread damage to the built environment throughout the Lake Champlain Basin in Vermont, New York, and Québec. Lake Champlain was above flood stage (100 feet or 30.5 m AMSL) from April 13 through June 19, 2011 reaching a record high level at 103.27 feet or 31.5 m AMSL.[63] Shoreline, tributary, and flash flooding along with rising groundwater and landslides plagued Vermont and New York. In Québec, over 25 communities were severely flooded by Lake Champlain's outlet, the Richelieu River.[64] Characteristics of the spring flooding included prolonged inundation, wave action, river damage, shoreline erosion and landslides. As a result, the Lake Champlain Basin experienced widespread damage to the built environment including homes, businesses, roads and public buildings along with electricity and energy resources.

Inundation Damage

The spring 2011 flooding was a prolonged eight-week event. During that time, homes and businesses near the Lake were inundated. Water damage or unequal pressure on foundation walls caused structural damage. Mold growth destroyed interior furnishings and structural materials in buildings. Flooded electrical wiring was a safety hazard, at times leading utilities to shut off power for whole neighborhoods. Corrosion, leaking, and disconnection of gas lines, propane gas tanks, and oil tanks was reported, further contaminating floodwaters and creating fire hazards. Septic systems overflowed, contaminating drinking water wells. For many who remained in flooded homes, rowboats or makeshift bridges were required to cross access their property.

The Richelieu River also inundated over 25 communities in Québec for more than two months, damaging or destroying 2,535 homes and displacing 1,651 residents. Of those displaced, many faced long-term displacement or permanent relocation.[65] Vermont Emergency Management reported damage to over 500 homes along Lake Champlain, 24 of which were destroyed. In New York, reports to FEMA indicate a total of 929 homes with major or minor damage and 19 homes destroyed.[66]

Wave Action

Lake Champlain is 120 miles (193 km) long with a north-south orientation, creating the ideal environment for northern or southern winds to generate wave action. During the spring flooding, wind from the south pushed water northward into the Richelieu River valley. In late May, 50 mph (80 km/h) winds pushed the Richelieu River surface level higher than the record set in early May.[67] Wave action, coupled with widespread inundation, severely damaged the built environment in the Richelieu region, already weakened from saturation and water damage. Residents reported waves spraying over homes, broken windows, and structural damage. The causeways linking the Lake Champlain Islands to the mainland in Vermont were threatened.

Fluvial Damage

The tributaries of Lake Champlain also flooded over their banks, at times with flash flooding causing damage to riverbanks and damaging the surrounding built environment. Flood waters swell over the banks gain momentum moving downstream colliding with buildings or eroding streambanks supporting structures. In addition, floodwater — containing sediment as well as other potential flood contaminants— was carried through towns and villages, leaving a thick layer of muddy silt in developed areas.

In late May, heavy rains triggered a flash flood through the Northern Branch of the Winooski River, washing through Vermont's capital, Montpelier, and surrounding areas. In Barre, every building within ten blocks of downtown suffered some damage and the City was covered in a layer of muddy silt three feet (1 m) deep in some places. In Montpelier, several business owners reported six to eight feet (1.8–2.4 m) of water in their basements.

Saturated Soil Damage

Prolonged spring flooding with heavy rain and snowmelt saturated the soil of the Lake Champlain Basin and elevated groundwater levels. A USGS groundwater monitoring network measured increased groundwater levels in Franklin, Lamoille, and Rutland counties in Vermont. Homeowners reported flooded basements and overflowing septic systems throughout the Lake Champlain region.

Saturated soil can increase the risk of landslides, an extreme form of erosion on steep slopes. In Barre, Vermont residents were evacuated when a 12-foot (3.6 m) section of hillside spilled onto Interstate 89, increasing the risk of more landslides.[68] On Porter Mountain in Keene Valley, New York, an 82-acre (33 ha) slow-moving landslide – the largest landslide in the State's history – crept along at 3 inches (7.62 cm) per day for the month of May, destroying one home and threatening several others.[69]

Tropical Storm Irene: August 28, 2011

Tropical Storm Irene brought torrential rains and strong winds to the Champlain Basin just a few months after the spring flooding. Irene had a greater impact on tributaries and valleys than on Lake Champlain, although the long-term effects on the Lake from the events are still unknown. Vermont and New York were heavily impacted while Québec was spared. Flash floods swept through urban centers, destroying infrastructure, agricultural crops and shoreline habitats.

Vermont

Statewide in Vermont, preliminary site visits from FEMA estimated that more than 3,535 homes suffered some damage and of those, 1,400 households were displaced.[70] Of the 7,233 Vermonters who registered for FEMA assistance, more than half were from counties within the Lake Champlain Basin. Floodwaters from Irene caused immediate structural damage to gas and oil tanks and distribution networks, and electrical infrastructure. About 73,000 Central Vermont Public Service customers were without power after Irene; power was restored to 55% of these customers within 24 hours and 100% were fully restored within a week.[71] Propane and oil tanks were a major hazard after Irene, especially in central Vermont where many residents rely on personal gas or oil tanks due to a lack of municipal gas lines. The United States Environmental Protection Agency (US EPA) and the Vermont Department of Environmental Conservation (VT DEC) addressed hazardous spills using oil-water separators, and processed 300,000 gallons (1,135,623 L) near the Waterbury State Complex alone. Addressing oil contaminants from Tropical Storm Irene cost an estimated $1.75 million.

Irene damaged public and emergency response buildings, compromising the ability of public services to mitigate the storm's impact. In Vermont, the Waterbury State Office Complex—home of Vermont Emergency Management and the Vermont Agency of Natural Resources—were flooded and employees were relocated to temporary offices.

Many staff within these agencies served as key responders to the Irene response effort, providing civilian emergency management and environmental mitigation as the storm progressed. The LaRosa Agriculture and Environmental Laboratory and the Vermont State Hospital were severely damaged in flooding to the Waterbury State Office Complex, with repairs costing up to $85 million.

There were 344 applicants for Public Assistance from FEMA. Of those 292 were deemed eligible by the end of 2012.[72] By December 2012, 3,056 of 3,225 individual flood response projects were funded by FEMA.[73] The Federal cost share (at 90%) obligated to Vermont was $129,601,374. There were 81 property acquisitions (buyouts) approved by FEMA.

New York

New York Governor Andrew Cuomo reported over $1 billion in damage statewide from Tropical Storm Irene. Upstate New York—including the Catskills, Mid-Hudson region and the North Country—experienced the most significant damage from Irene. According to the American Red Cross, 228 homes in the North Country were damaged or destroyed. Of those homes, 113 were damaged (30 destroyed) in Essex County and 111 were damaged (one destroyed) in Clinton County.[74] In the New York-portion of the Basin, Clinton, Essex, and Warren counties were declared as Federal Disaster areas, and Washington County was also declared to be in a State of Emergency following Irene. Statewide, over 900,000 New York homes were without power. New York utilities replaced over 300 miles (482 km) of wire in hard-hit areas.[75] Parts of Keene and Keene Valley were evacuated as the Ausable River flowed over its banks, jeopardizing homes and many public buildings were also severely damaged or destroyed in the New York portion of the Basin. The Upper Jay firehouse and library were both damaged costing at least $25,000 in repairs. In Keene, NY, the roof of the firehouse collapsed in the flood, further restricting emergency response in the area.

Existing Management

During the Flood

During both the spring Lake Champlain flood and Tropical Storm Irene, substantial measures were taken at the state and provincial, municipal, community, and individual levels to protect the built environment from floodwaters. Sandbags and other barriers, including cement barriers and rock pilings were used to hold back water or slow it down to prevent structural damage. During the spring floods, the State of Vermont filled over 67,000 sandbags and municipalities around the Basin stockpiled even more. Volunteers were a major workforce to stack sandbags and to remove them after the floodwaters receded. Many residents worked tirelessly to pump water out of their basements during the ongoing flooding. For some buildings, electricity was intentionally turned off to reduce electrical hazards. It was also recommended to secure or safely disconnect gas or oil tanks to reduce fire risks. State employees were dispatched to assist with safeguarding buildings and at-risk structures. State officials requested federal assistance from FEMA and the National Guard. In Québec, the federal government sent troops to aid evacuations and mitigation efforts during the worst part of the flood.

After the Flood

Inspection and Clean-up

While trying to limit damages to the built environment was tiresome for many, the major task was to fix impacts to the built environment after the flood. For many evacuees, returning home after the flood was shocking; it was the first time since the flooding began that residents could see the condition of their home.

State, provincial, and local governments urged homeowners to have their homes inspected for structural, electrical, and environmental health hazards. Operation of a well with an electric pump could lead to deadly electrical shock; a water-logged home with electrical damage is also very dangerous. Also, gas and oil tanks or gas lines in flooded homes could be causes of hazardous spills or fire.

Environmental health hazards are always a major concern when returning home after a flood event. It is recommended to remove any interior furnishing or drywall exposed to floodwater within 24–48 hours to prevent the growth of mold. Once mold is present, it is very difficult to eliminate within the structure. Mold growth is a potential environmental hazard promoted by excess of humidity and while often hidden, is not always easy to detect.

American Red Cross, SOS Richelieu, Canadian Red Cross, and several municipalities offered free services of building, electrical, and environmental health inspectors to reduce the costs of returning home for families and to mitigate mold growth. Extra measures were taken in hospitals and schools for children and adults vulnerable to mold-related illness. American Red Cross in Vermont and New York, as well as SOS Richelieu provided the public with free clean-up kits to support cleaning efforts. Donations also provided construction materials for flood victims.

A flooded neighborhood in Colchester, VT. Photo: LCBP

Reported Damages

One of the major challenges for managing flood damage to the built environment was the task of reporting damages, both on an individual and at a community level. Reporting damages was the first step in order to qualify for public and individual assistance and financial support. Many people in the region had never experienced such a severe natural disaster, and did not know how to report damages. Municipalities, regional planning commissions, and non-profit organizations worked together with state and provincial governments to facilitate the damage assessment and reporting from the 2011 flood events.

Management Needs

- Develop a framework for flood damage reporting that will encompass all communities and provide assistance for damage compensation

- State and Provincial agencies should develop simple reporting forms to circulate to municipalities affected by flood events. These reporting forms should be clear and easy to complete, but also provide information required by relevant Federal, State, or Provincial Emergency Response agencies.

- A Basin-wide GIS-based emergency response tool (such as a mobile application) should be developed and made available to first responders to facilitate information sharing.

Public Health Recommendations:

- The shorter the timeframe to reintegrate people into their homes, the lesser the damages, personal loss, health problems and distress will be.

- In preparation of a future disaster,
  - Develop syndromic surveillance methods to employ pre- and post-disaster
  - Introduce sensitive and specific call codes adapted to the event
  - Clarify sharing of responsibility for communication between public health and public security concerns, including incident command system protocols
  - Produce timely public reports to maximize information learned from the event
  - Develop better outreach materials for occupants of affected homes on proper treatment and eradication of mold and other environmental hygiene concerns

Information Gaps & Data Needs

Information Gap: Quantification of damages to the built environment caused by the 2011 flood events, including economic costs of damages, business lost (or gained) and the cost of repairs.

Data Needs:
- Survey of flood damages to built environment
- Cost-benefit analysis of rebuilding necessary infrastructure in flood-prone areas

Information Gap: Which communities are excluded in the existing reporting framework?

Information Gap: How much damage to the built environment has gone unreported?

Data Needs:
- Collect input on a municipal level through community-based focus groups to establish a reporting framework with a clear hierarchy of collecting state- or provincial-wide, or watershed-wide damages.
- Ensure that data collected by focus groups can be used by municipal, state and federal agencies in a cost-effective way.

Infrastructure

In the Lake Champlain Basin, much of the transportation infrastructure is located adjacent to waterways. Most major state routes, municipal and county roads, railroad lines, bridges, culverts, and recreational paths intersect or follow alongside the Lake or its tributaries and suffered substantially from the flood events. Dams of varying sizes and uses are scattered throughout the Basin. Drinking water, wastewater, and stormwater infrastructure are naturally close to waterways. Thus, flooding events put much of the Lake Champlain Basin's infrastructure a structural or safety risk due to hazard, chemical, or biological contamination. During the 2011 flooding events, every single community impacted by floods was broadly impacted by transportation damages.

Transportation: State Highway Systems & Municipal Roads

Spring Flooding – Vermont

According to Vermont's Agency of Transportation, State road maintenance and repair from the exceptionally heavy winter snowfall and the spring 2011 Lake flood totaled $15 million. According to Vermont Agency of Transportation and FEMA, public damages as a direct result of the spring flooding and $1.9 million in damage was suffered by state roads and highways. On Vermont roads, 14 different sites reported major slides and slope failures along rivers and streams.

During peak flooding, the State Route 2 Causeway between Colchester and South Hero was at risk of total inundation, which would isolate the southern Champlain Islands from Vermont's mainland. Sections of several other major State Routes (2, 7, 17, 36, 78, 118, 122, 125, and 129) were damaged, closed, or reduced to one lane. Interstate 89 roads and bridges totaled about $6 million, southbound near the Colchester exit was reduced to one lane due to partial inundation.[76] In rural regions of Vermont, municipal-owned back roads posed additional issues, as many of these are dirt roads that easily erode. The heavy rains that led to the Lake flooding damaged roads near headwater streams. Roads along the Mad River experienced severe damage, exceeding municipal road budgets early on in the year with costs around $1 million.[77]

Spring Flooding – New York

In New York, spring flooding caused just as much damage to transportation infrastructure as in Vermont. Spring floods caused nearly $2 million in damages to bridges and roads in Essex County; of this, $1.5 million in damages were in the town of Moriah, where many roads were washed out and two bridges collapsed. In Lake Placid, State Route 73 was narrowed to one lane due to encroaching floodwater and closed for bridge hazards in other locations. In Clinton County, much of Lake Champlain's shoreline was flooded, especially along the mouth of the Chazy River, inundating several roads.

Tropical Storm Irene – Vermont

Statewide, over 200 towns reported transportation damages in Vermont as a result of Tropical Storm Irene. According to the Vermont Agency of Transportation, Irene damaged over 500 miles (800 km) of State roads and 200 State bridges of the Vermont state highway system, costing $175 - $250 million to rebuild statewide.[78] Local road damages included 2,260 road segments, closing 175 roads and 90 bridges. Damage was done to over 960 culverts and

U. S. Route 2 causeway between South Hero and Milton, VT. Photo: LCBP

Vermont's eleven Regional Planning Commissions collected damage assessments and facilitated information and resource sharing. Damage to transportation infrastructure, at its peak, isolated thirteen communities across the state.

Tropical Storm Irene – New York

The New York-portion of the Lake Champlain Basin also sustained remarkable damages to transportation infrastructure from Tropical Storm Irene. In fact, most of the damage from Irene in New York statewide was suffered upstate. New York and U.S. Federal authorities reported 150 major highways in upstate New York were damaged by Irene.[79] In Essex County, more than 100 roads were damaged. According to Essex County Department of Public Works, between the spring floods and Irene, Essex County suffered damage to 10 bridges, 357 miles (574 km) of highway, 380 culverts and 15,000 feet (4,570 m) of roads were washed out.[80] Route 73 of New York State's Highway system was washed out and undermined in several places. NYS Department of Transportation reported that Route 73 was reopened by the end of September. In the Lake George region, NYS Highway routes 9 and 9N, along with several local roads were washed out and closed. Runoff in the area overwhelmed the local culvert and stormwater management systems. Warren, Washington, and Saratoga counties were declared states of emergency with several road closures from the Mettawee River and the Battenkill.

Rail Line, Transit, and Airports

The major railroad network in the New York-portion of the Basin is Canadian Pacific, crossing the South Lake and running along the western Lake Champlain shoreline. During the spring 2011 flooding the Amtrak operation along the Canadian Pacific Railroad was suspended due to the high Lake level. During Tropical Storm Irene, Canadian Pacific railroad was closed for several days, prior to the storm, during the storm, and in some areas after the storm for high water or fallen trees, but was quickly repaired. In Vermont, the state-owned railroad suffered a total of 107 washouts (50 of which were major), significant damage to six bridges and over 200 miles (320 km) of railroad with an estimated cost of repairs at $21.5 million. New England Central Railroad, a privately operated railroad in Vermont, required repairs in 66 locations.[81] Aside from potential structural damages during times of flooding, railroads are relatively resilient to floodwater and can operate in shallow floodwater.

Irene also impacted public transportation by bus in Vermont, flooding Green Mountain Transit Agency's Berlin office and damaging 13 vehicles. The Hartness Airport in Springfield, Vermont and the Newport Airport also sustained some damages.

Recreational Paths

The flooding events had a major impact on recreational paths throughout the Lake Champlain Basin. The Lake Champlain Byway, Island Line, and the Chambly Canal Multipurpose Bike Path to name a few, are models for recreational pathways and serve as a tourist attraction. The flooding events caused serious damage to this recreational infrastructure. Parts of the Island Line Bike Path in the Burlington area suffered from sink holes, impacting the Burlington City Marathon course. The Colchester-South Hero Causeway connecting bikers from the Burlington Bike Path to the Champlain Islands was severely washed out with major trail damage. Much of the trail leading up to the causeway was also washed out. To date, much of the trail is not accessible and the bike-ferry connecting the causeway has remained closed since the spring floods. In Québec, the Chambly Canal multipurpose paths were closed due to exceptionally high waters along the canal and associated risks.[82]

Upland in the Basin, hiking trails and trail drainage infrastructure suffered damages mostly from Tropical Storm Irene. The Green Mountain National Forest reported multiple trail, recreational site, and road closures, and as of November 2011, following Irene, 20 trails, five recreational sites, and 20 roads remained closed. Vermont State forests and parks also suffered damages; as of November 2011, 33 roads, 14 trails, several bridges and a canoe access area still required repairs. Damage to state forest roads restricted timber sales in managed forests. The Green Mountain Club reported trail closures after the storm, and worked to clear downed trees from their trails. Though several months away, winter recreation was also impacted; the Vermont Association of Snow Travelers trails were damaged and remained closed to snowmobiles the following season.

Recreational paths in New York State's Adirondacks also suffered significant damages from the spring floods and Tropical Storm Irene. Many areas damaged from the spring floods were not fully recovered by the time Irene hit the region, further deteriorating the condition of many trails. Irene damage spanned the Eastern Adirondacks from Moriah to Keene Valley and into the Lake Placid region, impacting trails in the Eastern High Peaks of Giant Mountain and Dix Mountain. The bridge over Marcy Dam, a popular hiking destination in the High Peaks, was washed away and Marcy Dam itself was leaking. Floodwaters overflowed the dam and flooded out the trail downstream. Also, the Duck Hole Dam was breached.[83]

Flooding along the Ausable River caused a record 12 feet (3.6 m) over flood stage with further damage to access to the Ausable Chasm, a major tourist attraction. The Adirondack Loj, a major starting point for hikers in the High Peaks region, was isolated when the bridge on Adirondack Loj Road washed out stranding 31 visitors and staff. Access to the region and several trailheads were limited by washouts and road closings along State routes 73 and 9.[84]

Water Transportation

The spring 2011 Lake flooding severely impacted transportation by water on Lake Champlain and the Champlain Canal. Lake Champlain Transportation Company links Vermont and New York by car ferry in three different locations, and at the time of the flood events, a temporary ferry connected Vermont and New York at the location of the Crown Point Bridge while it was being rebuilt. At times, high Lake-levels limited ferry access at the docks or roads accessing ferries. Access to the temporary Crown Point ferry was limited by flooding on Route 185 in Vermont. Other ferries were slowed and forced to a reduced schedule. The ferry connecting Charlotte, VT and Essex, NY was shut down due to a flooded landing for nearly a month between April 28 and May 26 due to high waters.[85] These ferries are a major component of transportation infrastructure in the Basin and used daily by commuters.

In spring 2011, boating on Lake Champlain for recreation or commercial purposes was hazardous and limited. Conditions for boating were unsafe with substantial debris floating in the Lake from damaged lakeshore structures. Marinas, docks, and boat launches were flooded, limiting access to the Lake by boat. In addition, large boat wakes could cause severe damage to the newly inundated lakeshore, where wave-action and wet conditions were already creating severe erosion. For these reasons, boat operators were urged to not navigate Lake Champlain.

The Champlain Canal delayed opening in spring 2011 due to high water levels. High water levels increase the velocity of water flow impacting the navigation functions of the Canal. Also, flooded communities along the Canal would be put at greater structural risk if canals were open to boating despite flooding, with wakes causing damaging wave action. Typically, the Champlain Canal is open around May 1st; the Canal opening was delayed about one month due to the spring flooding. The Canal initially opened to commercial boat traffic, including barges. This caused great concern amongst communities along the Canal, worried that the wake of large barges could severely damage flooded areas. Lock 12, connecting the Champlain Canal to Lake Champlain, was the last lock to open after the flooding. Boaters were urged to navigate at no-wake speeds to reduce damage to any land still inundated.[86] Tropical Storm Irene also led to the closure of the entire Champlain Canal system for about two weeks.

As the spring 2011 floodwaters rose in Québec, the Chambly Canal was closed to prevent damage to nearby properties. The Chambly Canal was delayed in opening until July 1, 2011, two weeks later than usual. Parts of the recreational path along the canal were badly damaged during the flooding, and were not re-opened until mid-July of 2011.[87]

The canal itself was drained and remained closed during the spring flooding, suffering little to no damage. During Tropical Storm Irene, the Erie Canal in central New York was forced to close, trapping over 250 boaters in the New York State Canal system. The Chambly Canal remained open until October 31, 2011 (one month later than usual) to facilitate navigation of waters to and from the Erie Canal.[88]

Dam Infrastructure

The exact number of dams in the Lake Champlain Basin is unknown, but dams of varying size and design are scattered throughout the Basin, some privately owned and some publically owned. Many dams no longer serve a major purpose and are not maintained. During times of flooding, dam infrastructure may be compromised.

Flooding puts old dams at risk of structural damage or collapse, potentially causing severe flooding downstream. Dams that are fully operational may control flooding upstream or downstream. Operators are faced with the challenge of managing water flow during severe flooding to not compromise the structural integrity of the dam, while also preventing severe flooding upstream or downstream. An example of this is the Lake Flower Dam in the Village of Saranac Lake, New York—a water retainment dam that doubled as a bridge—for Main Street. At this particular dam, upstream flood pressure forced operators to release water in small increments. Despite these measures, upstream flooding persisted and began to undermine the surrounding land. To reduce hazards, the dammed portion of Main Street was closed to traffic. The flood gates were opened as far as possible to release water without severely damaging the buildings or the town's water main downstream. As a result areas downstream from the dam were forced to evacuate.

Similarly, the Marshfield Dam on the Winooski River upstream from Montpelier, Vermont was at risk of floodwater overflow. Operators realized they may need to open floodgates as an alternative to a dam overflow and possible breach. City officials downstream of the dam evacuated at-risk areas. Fortunately, the water levels stabilized and significant additional flooding was avoided.

Though there were news reports of Waterbury Dam releasing water during the spring flooding, no controlled release occurred. The reservoir level reached its third highest peak of 605.3 ft (185 m) on April 29, 2011, forcing water over the dam's spillway. The peak was not considered to be a major flood stage, so the gates were never opened.[89] Waterbury Dam was built as a flood retention structure to protect the town of Waterbury. Though Waterbury was heavily affected by Tropical Storm Irene, the dam held back a significant amount of water and is widely believed to have served its purpose by protecting the town below. As a result of both flood events in 2011, the dam suffered significant structural damage, which has since been repaired by the U.S. Army Corps of Engineers.[90]

A few smaller dams were reported to be damaged in upstate New York. The Upper Jay Dam located on the Eastern Branch of the Ausable River was undergoing decommission plans by the Town of Jay and the Ausable River Association to improve aquatic organism passage. When Tropical Storm Irene flooded the region, the dam was damaged. Consequently, the NYS Department of Environmental Conservation (NYS DEC) executed an emergency authorization to remove the Upper Jay Dam and the reservoir is now drained. In the High Peaks region of the Adirondacks, the Marcy Dam and the Duck Hole Dam were partially breached due to damage.

Water and Wastewater Infrastructure

Flood events can impact water and wastewater infrastructure. Broken pipes from flood damage reduce pressure, increasing the likelihood of compromised drinking water supplies. Drinking water systems, water intake pipes, private wells and municipal water networks may be at risk of contamination by floodwaters. Wastewater treatment facilities are generally located along the Basin's waterways at low elevations, close to receiving streams. Low elevation help with pumping efficiency. The lower the elevation of the plant, fewer pump stations are necessary because the plant can be gravity-fed from homes. In most cases, facility operators have emergency response procedures allowing facilities to continue operating very soon after a flood. In past flooding events, wastewater treatment facilities have endured well, but with climate change and more frequent extreme storm events, low-lying plants, such as Johnson, VT, have taken action by installing storm doors (watertight ship-style), and raised tank walls. Modern generator sets are now elevated, however the cost of upgrades is significant and not all plants are prepared for an event like Irene.[91]

Flooding of wastewater treatment facilities may lead to contamination through:

- Effluent pipes—where water is discharged from a facility into the receiving water—are stationary along the Lake or a tributary. If floodwaters rise above the effluent pipe, floodwater could back-up into the facility through the effluent pipe, even if floodwaters have not reached the facility itself. This happened to the Montpelier Wastewater Treatment Facility during the Winooski River flash flood in late May of 2011, where floodwater backed-up the effluent pipe flooding within the facility, but very little wastewater was discharged untreated.[92]
- Combined sewer overflows (CSOs), used to collect stormwater runoff during severe weather, and may overburden a wastewater treatment facility during flooding, forcing the operator to release untreated wastewater into the receiving body of water.
- Floodwaters could enter the wastewater treatment facility itself, carrying untreated water when flood recedes.
- Floods also present the risk of contaminating water resources from inundation of septic systems

In the spring flooding, there were a few minor failures in the wastewater treatment infrastructure, along with some associated risks. E. *coli* contamination was reported in water supplies for Port Henry, Essex, and Willsboro, New York. These communities were all under boil water advisories, affecting approximately 3,600 people.[93] Water suppliers increased treatment with chlorination and filtration to address increased turbidity.

Damage from Irene to water infrastructure was much more severe. E. *coli* contamination was reported for water supplies in Clinton County, and the towns of Port Henry, Essex, and Willsboro in New York and in 30 public water systems in Vermont. Seventeen wastewater treatment facilities in Vermont reported compromised operations with varying issues related to flooding. Most of the problems were resolved within 24 hours to one week after the flooding, resulting in an estimated 10 million gallons of untreated sewage discharged during this period state-wide.[94]

Existing Management

Transportation Agency Response

Transportation infrastructure is typically the first compromised entity of the developed environment during flood events. At the same time, transportation access is crucial for emergency responders to minimize hazards to human health and safety. During the 2011 flooding events the first priority was to maintain or restore access to communities isolated by floodwaters.

During the spring flooding events, Vermont's Agency of Transportation and New York's Department of Transportation worked to make repairs and keep roads open to the extent possible. In some instances road were closed, lanes reduced and detours created. Transportation officials attempted to make repairs and keep roads open. As the flooding continued it became apparent that it would be a prolonged period of inundation and immediate repair was not a realistic or economical use of transportation resources. Mitigation efforts for flooded transportation infrastructure priority quickly shifted to establishing detours and closing roads that were hazardous to drivers. For some communities, such as the Champlain Islands, detours were not possible. In these scenarios, the priority was to maintain a navigable roadway by installing cement road barriers in an attempt to keep water and floating debris away from the roadway. Some roads required narrowing to one lane, and road crews or local law enforcement officers were necessary to direct traffic on busy roads through one lane.

Responding to transportation infrastructure damage is costly, requiring substantial resources in a short timeframe, including structural materials and sandbags to hold back floodwaters.

Quarries worked overtime to provide enough stone for side slope repairs. The Whitcomb Quarry reported double the daily average of stone production, with Vermont road crews picking up over 6,000 tons of stone each day during the spring floods.[95] By the end of the spring floods (prior to damage from Irene), many municipalities found it difficult to secure the funds needed to maintain Town roads. In the Mad River Valley, Duxbury, VT a community of 1,600 people faced $1 million in spring road damages from flooding.[96] Across the Lake, Moriah, New York, a community of just over 4,500 people operating on an annual budget of $2.8 million, faced $1.5 million in damages from spring floods.[97] Other small towns, including Peru, had to reallocate funding from other budgets and hope for financial aid to compensate for funds expended on road repairs. In Isle La Motte, VT funds were spent on rock pilings to reinforce shoreline roads from high-water and wave action. For many communities large portions of their annual budget were forwarder-allocated to infrastructure repairs with the hope of receiving assistance for financial relief from government agencies.

Transportation management during flooding also requires an enormous workforce. Vermont, New York, and Québec tapped into a network of road workers to maintain roads on an emergency level including state and provincial road crews, municipal road crews, law enforcement officers, contracted workers, and the National Guard in order to maintain or restore access to communities throughout the flooding events. Tropical Storm Irene recovery brought additional assistance by National Guard troops from seven states, New Hampshire Department of Transportation staff and equipment, and 120 Maine Department of Transportation road workers.[98]

Immediately following Irene, the Vermont Agency of Transportation (VTrans) closed 146 state road segments and 34 bridges totaling 531 miles (854 km).[99] Three different incident command centers were opened throughout Vermont to report transportation damages and organize response efforts. VTrans established detours and prioritized connecting isolated communities. In addition, VTrans provided significant resources to the state's regional planning commissions so they could assist Vermont municipalities in assessing the damage and working with FEMA on addressing the impacts. Also, VTrans worked closely with utilities to restore power and telephone services. The damage was so immense that the last mile of work was not completed until the end of December 2011. VTrans recruited assistance from 200 private contractors accounting for 1,800 workers from the private sector, primarily from Vermont. VTrans also partnered with 150 workers and 145 pieces of equipment from Maine Department of Transportation, and 75 workers and 60 pieces of equipment from New Hampshire Department of Transportation. National Guard Troops assisted from Vermont, Maine, Illinois, Ohio, New Hampshire, South Carolina, West Virginia, and Virginia.

Railroad Repair

Vermont Agency of Transportation facilitated the recovery of Vermont railroad systems. They contracted six contractors and engineering firms. Repairs lasted 21 days, working 24 hours per day. To accelerate the recovery effort, the State of Vermont temporarily waived environmental regulations and weight restrictions. The Vermont Rail System, a state-owned railroad, coordinated efforts and shared resources with the New England Central Railroad to expedite the repair process.

Management Needs

Preparation for Future Severe Weather Events

Stormwater infrastructure is an essential component of transportation infrastructure. This infrastructure, including culverts, drainage ditches, swales, bridges, and river access to the floodplain, must be improved through upgrades and retrofits. Much of this work is already being accomplished on a local level, but upgrades are primarily voluntary and grant-driven in all but MS4-designated communities. All jurisdictions of the Lake Champlain watershed must inventory their stormwater infrastructure, provide proper funding, and make appropriate changes. Development of a framework for reporting damages and data collection through public works entities is an ideal way to achieve this goal in a cost-effective manner. In the case of improving stormwater infrastructure, the major incentive is to reduce up- and downstream hazards, increase the life of the structure and avoid repair and replacement costs. Lost tourism is an important secondary impact. With undersized culverts, drainage, or damaged roads, tourism dollars are lost for closed roads. Undersized culverts may impair aquatic organism passage, and require more expensive emergency maintenance resulting from storm events. Emergency repairs or replacement can be four- to 140 times more expensive than scheduled maintenance. Sufficiently sized, natural bottom-arch culverts improve aquatic organism passage, and do not need to be replaced as often as round culverts that are less effective for aquatic organism passage. The ecosystem functions properly by sizing culverts to manage fluvial erosion hazards and stormwater, while allowing aquatic organism passage. Proper sizing also improves infrastructure durability that can weather increasingly intense storm events.

Informing Road Workers

An educational approach is being taken in New York and Vermont to educate transportation engineers, technicians and maintenance personnel road workers on basic river science both in terms of design and operating equipments in and near waterways. The agencies are considering comprehensive ways to manage transportation infrastructure to reduce vulnerability and flood risks. NYS Department of Environmental Conservation (NYS DEC) recommends using a three-prong approach to build long-term commitment to improving infrastructure for transportation operations. First, increase awareness on how storm events impact streams and associated infrastructure. Second, educate engineers and operations personnel on stream mechanics relevant to their jobs. Third, distribute manuals on planning, designing and maintaining the transportation networks while restoring streambanks. The overarching goal for New York, Québec and Vermont is to strengthen partnerships and communication between environmental and transportation organizations so that policies and practices can be improved to address long term flood resilience.

- Improve Bridge and Culvert Designs and Stormwater Infrastructure by making adjustments to account for changing climate, with storm events increasing in intensity.

- Strengthen partnerships, planning and policy making between environmental and transportation agencies in order to design and build safe, affordable and ecologically sound transportation infrastructure in the Lake Champlain Basin that is resilient to a changing climate.

- Identify and mitigate any risks associated with dam structures in the Lake Champlain Basin to reduce flood hazards and improve ecological connectivity.

- Increase the resilience of public and private water system infrastructure in the Lake Champlain Basin to reduce risk of contamination to water bodies and water supplies. Train wastewater treatment facility operators on appropriate management options to implement during natural disasters.

Information Gaps and Data Needs

Information Gap: What is the vulnerability and risk to transportation infrastructure and how can the jurisdictions prioritize their resources to address that risk? What is the status of culverts and other stormwater infrastructure in the Basin? How can we change policy and create funding to provide necessary improvements.

Information Gap: How many dams exist in the Lake Champlain Basin? Which structures are abandoned and outdated creating a hazard to downstream communities and reducing ecological connectivity.

Data Needs:
- GIS Inventory of all culverts in the Lake Champlain Basin
- An assessment on the cost of retrofitting inadequate culverts (those that failed in the floods of 2011 or have been listed as in need of repair)
- Determine methods to identify vulnerability and risk to transportation infrastructure from future flooding on a watershed basis.
- A hydrology model with various climate scenarios to identify susceptible watersheds, vulnerable infrastructure and at-risk communities

- Identify necessary water system structural upgrades
- Create an inventory of dams in the Basin
- Prioritize dams necessary for decommission

Economic Impacts

Public Expenses

Short-term, the economic impact of the 2011 flooding events was largely in public expenditures to restore necessary infrastructure and access to emergency services. Québec was hit hard during the spring floods, with early estimates costing the provincial government $2.4 million to evacuate and accommodate displaced residents.[100] As the flooding persisted for nearly two months, costs rose to over $70 million in the Québec portion of the Basin.

The spring floods caused financial burdens in Vermont and New York in two parts: first, the emergency evacuation of headwater residents during torrential rain events, then providing aid for shoreline homeowners and infrastructure. In Vermont, there were 800 claims to FEMA and $3.6 million awarded in public assistance in the Basin after the disaster declaration mid-summer.[101] In New York, 900 claims for assistance went to FEMA, with $9.9 million awarded within the Basin.[102]

When Tropical Storm Irene hit the area, the Vermont Agency of Transportation suffered $8 million in damage to transportation infrastructure. FEMA paid $1.8 million to individuals and $8.6 million to cities, towns, and the state of Vermont to cover public costs. Tropical Storm Irene directly affected 230 municipalities with restoration costs between Vermont and New York totaling $150 million Basin-wide.

Local Economy

The spring 2011 Lake flood heavily impacted local businesses, especially those reliant on summer tourism and recreation. In the early stages of the spring flood, Vermont local tour and cruise business *Spirit of Ethan Allen* spent $5,000 in dock and electrical adjustments as its home port flooded.[103] Further flooding of docks and marinas limited boating on Lake Champlain. The Lake Champlain Community Sailing Center delayed opening from flooding from late April to July, resulting in a loss in program revenue of $50,000 plus an additional $25,000 in damages.[104] Whitehall Marina (NY) lost an estimated $50,000 of their $250,000 annual revenue from damages and delayed opening.[105] In total, business along the Champlain Canal was down 25% from flooding in conjunction with high gas prices.[106] Essex County, New York had a retaining wall and several docks washed away and the 21-week tourism season was shortened by six weeks.[107] Burlington waterfront's boathouse, home of Splash delayed opening and cancelled private events. In Québec the Camping-Plage Kirkland campground had damage to many customer's trailers.[108]

Long-term socioeconomic impact of the flooding that occurred has not yet been determined. Socioeconomic impact may be seen long-term in damage to tourism attractions throughout the Basin, especially if flooding and unpredictable weather patterns continue to increase damage costs on an annual basis. In other cases, damage to office complexes, downtown areas, and small businesses has an impact on the revenue for businesses, as well as the businesses supported by employee traffic in the local economy. The Waterbury State Office Complex, including the LaRosa Agriculture and Environmental Laboratory and Vermont State Hospital, flooded, displacing approximately 1,500 employees from the Waterbury area.

Some of the facilities were permanently closed. Not only were the jobs of these employees impacted, but the business they brought into Waterbury's local economy was driven elsewhere. This is an example of how local economies may be impacted long-term from flood damages.

Existing Management

Sources for Funding

Despite the outstanding damages caused by both flooding events, sources of funding and support have been made available by local, state, and federal organizations, as well as community groups and non-government organizations.

Federal

United States federal financial support includes sources from the Federal Emergency Management Agency (FEMA), the National Flood Insurance Program, and the Small Business Administration. The Internal Revenue Service (IRS) postponed deadlines for business owners and individuals in disaster areas.

State or Provincial

State or Provincial agencies provided financial assistance, as well as services and supplies free of cost. Vermont established a variety of recovery programs through the *I am Vermont Strong* campaign. The Vermont Disaster Relief Fund administered much of the fundraising, donations, and local recovery funds, working with the Vermont Voluntary Organizations Active in Disaster and Vermont Emergency Management for long-term recovery. The Vermont Agency of Commerce and Community Development, the Vermont chapter of Associated General Contractors, the Community Foundation, and the Mobile Home Project developed the Mobile Home Deconstruction Program.

The State also served the communities through the Community Recovery Partnership, an initiative to engage communities in the recovery process to identify needs of communities, and develop plans for recovery.

While New York did not receive federal funding for individuals from the spring floods, public financial aid was granted. Compensation for damages from Irene was granted public and individual FEMA assistance. In New York, Governor Cuomo organized the "Labor for your Neighbor" movement facilitating over 2,000 volunteers in response to Tropical Storm Irene. In addition to this, the State of New York received a $16 million grant from the United States Department of Labor for NY Works: Neighborhood Rebuilding Corps, hiring several hundred unemployed New Yorkers for three months to support Irene recovery efforts employed by the New York State Department of Labor.[109]

In Québec, individual assistance for damaged homes compensated owners up to $150,000. The provincial government also provided funds for those displaced to stay in hotels until they could return home, totaling approximately $2.4 million.[110]

Local and Community

Nine volunteer Long-Term Recovery Committees have been set up throughout Vermont following Irene, administered by county or town government, community groups, and volunteers. The Long-Term Recovery Committees work with federally funded case managers to implement recovery plans with funding from the Vermont Disaster Relief Fund. Municipal government played a major role in recovery by reporting damages in order to obtain federal funding.

Non-government Organizations

Non-government community based organizations rose from the destruction of the 2011 flooding events. In Québec, SOS Richelieu facilitated in reporting damage, seeking financial assistance, and connecting victims with free services. SOS Vermont helped individuals with psychological support and connecting them with local resources. Many organizations including local government, volunteers from SOS Vermont, and Red Cross provided financial planning workshops for flood victims as referenced in other sections of this report. Regional planning commissions also played a huge part in compensating for lack of county government in some areas.

Fundraising

The Vermont and New Hampshire Valley Red Cross provided services throughout the 2011 flooding events with requests for donations from the public along with requests for volunteers partnering with Salvation Army and Volunteer Organizations Assisting Disasters (VOAD). To raise funds, the Red Cross partnered with local news stations Fox 44 and ABC 22, to help spread the message of damage caused by the flooding, sharing stories and requesting financial assistance from the public through the media. Encouraging donations through media, the New England Federal Credit Union offered a generous $10,000 challenge grant, challenging the public to pool $10,000 to match the credit union's pledge. Additional Red Cross partners include: Casella Waste Management, Blue Cross Blue Shield of Vermont, NBT Bank, and Vermont Telephone. Fundraising was critical for the Red Cross, because the spring disaster alone put them at a $200,000–$300,000 budget deficit for the year. In July, a Berlin Mall raffle raised $3,000 in funds to go toward spring flooding relief.[111]

Tropical Storm Irene created an even larger demand for Red Cross and other relief services in Vermont, and fundraising proved to be an enormous source of funding for flood victims, showing continued support beyond the scope of the storm itself. Green Mountain Coffee Roasters provided a generous $250,000 gift to the American Red Cross to meet immediate need ($75,000), develop a community sheltering model for future disaster events ($125,000), and the remaining $50,000 was split between American Red Cross of Central and Western Massachusetts and the American Red Cross of Eastern Massachusetts to assist with Irene-related relief. Additionally, the Newman's Own Foundation grant pledged $30,000 to the Vermont and New Hampshire Valley Region of American Red cross to support the community sheltering initiative. Newman's Own Foundation provided $150,000 in grants to five Vermont organizations to address the wake of Tropical Storm Irene. Sentinel Investments donated a holiday gift of $15,000 to the American Red Cross to contribute to improving preparedness for community shelters.[112]

A major fundraiser for Tropical Storm Irene relief included several benefit concerts from local artists. Concerts included the Waterbury Good Neighbor Benefit Concert, on September 16th following Irene; Green Mountain Coffee Roasters sponsored a concert with local artists Rubblebucket and Ritmo Masacote at Higher Ground in South Burlington to support the Vermont Food Bank. Vermont bands *Phish* and *Grace Potter and the Nocturnals* each held fundraising concerts.

The American Red Cross Northeastern New York (ARCNENY) supports the New York region of the Lake Champlain Basin. During and beyond the spring flooding and Irene, residents, local businesses, media, and corporate partners fundraised to support relief efforts. Price Chopper stores in New York, Massachusetts, Vermont, Connecticut, and New Hampshire (all states with store locations) teamed up with Red Cross to fundraise for Irene through the "Your Help Counts: Irene" pin-up campaign matching the first $10,000 in donations. SEFCU Bank also collected donations at any of their branch locations matching the first $25,000 donated. Time Warner Cable donated $25,000 in cash to American Red Cross along with $25,000 in local media to support recovery efforts for Irene. In total, New York's corporate partners' donations added up to $167,000 within the first few weeks of recovery.[113] Beyond the immediate recovery, Dunkin' Donuts donated $66,823 through customer donations and provided a match of $10,000.[114]

Management Needs

- Increase availability of flood recovery assistance to impacted communities
- Provide incentive to mitigate the impacts of future flooding events through cost-benefit analysis.

Information Gaps and Data Needs

Information Gap: What is the actual economic impact of the 2011 flooding events?

Data Needs:

Complete an economic impact analysis of the 2011 flooding events on a watershed level through the following:

- Quantify the economic cost of the 2011 flooding events accounting for direct damage to economy: reduced revenue for local businesses, costs of public services, and rebuilding.
- Quantify damage to ecosystem services including loss of fish and wildlife, damage to forested land, recreation and aquatic habitats.

Information Gap: What was the economic impact of the 2011 flooding in comparison to the cost of improved flood management techniques at a watershed level?

Data Needs:

- Complete a cost-benefit analysis accounting for positive externalities of flood management on an environmental and socioeconomic level including but not limited to: increased riparian habitat and recreation, improved water quality, floodplain zoning, and risk mitigation.

Keene Valley, NY post-Irene.
Photo: SUNY Plattsburgh/Lake Champlain Research Institute

Endnotes

36. Québec Civil Protection (Sécurité Publique Québec), Report, May 2011 (http://www.barreau.qc.ca/pdf/publications/2011-inondations.pdf) accessed September 2012.

37. Québec Civil Protection (Sécurité Publique Québec), Report, May 2011 (http://www.barreau.qc.ca/pdf/publications/2011-inondations.pdf) accessed September 2012.

38. Canadian Red Cross News Report “Montérégie Floods: The Red Cross Preparing for the Recovery Phase” June 15, 2011 (http://www.redcross.ca) Accessed July 2012.

39. Canadian Red Cross News Report “Montérégie Floods: The Red Cross Preparing for the Recovery Phase” June 15, 2011 (http://www.redcross.ca) Accessed July 2012.

40. VT ANR Irene Report, December 2011, http://www.anr.state.vt.us/anr/climatechange/irenebythenumbers.html.

41. National Grid Upstate New York Press Release, September 1, 2011 (http://www.nationalgridus.com/aboutus/a3-1_news2.asp?document=6334). Accessed July, 2012.

42. Doug Kievit-Kylar, Vermont Department of Environmental Conservation, Drinking Water and Groundwater Protection Division, personal communication, 12/7/11.

43. Bilan de la mobilisation de l’ORSC relativement aux inondations en Montérégie (2011) Agence de la santé et des services sociaux de la Montérégie.

44. Drinking Water Supply Division of Vermont Department of Health (http://www.vermontdrinkingwater.org/).

45. Doug Kievit-Kylar, Vermont Department of Environmental Conservation, Drinking Water and Groundwater Protection Division, personal communication, 12/7/11.

46. NYS Department of Health (http://www.health.ny.gov/).

47. Elizabeth Royer, VT Rural Water, personal communication; Essex County (NY) Office of Community Resources.

48. QC MDDEFP Potable Water (http://www.mddep.gouv.qc.ca/eau/potable/index-en.htm).

49. Agence de la santé et des services sociaux de la Montérégie

50. Starting Over Strong Vermont June 2012 News Release (http://startingoverstrongvermont.org); Accessed July 2012.

51. New York State Office of Mental Health Project Hope (http://www.omh.ny.gov/omhweb/disaster_resources/project_hope/).

52. FEMA News Release Series DR-4020 (https://www.fema.gov/disaster/4020/news).

53. Vermont Red Cross Disaster Alert May 27, 2011 (http://newsroom.redcross.org/).

54. FEMA Disaster Declaration DR-1995, June 15, 2011 (http://www.fema.gov/pdf/news/pda/1995.pdf).

55. FEMA Disaster Declaration DR-1993, June 10, 2011 (http://www.fema.gov/pdf/news/pda/1993.pdf).

56. VT ANR Irene Report, December 2011, http://www.anr.state.vt.us/anr/climatechange/irenebythenumbers.html.

57. Vermont Red Cross News Release, September 1, 2011 (http://newsroom.redcross.org/).

58. Vermont Red Cross News Release, September 1, 2011 (http://newsroom.redcross.org/); American Red Cross Fast Facts.

59. Vermont Red Cross News Release, September 1, 2011 (http://newsroom.redcross.org/).

60. Vermont Red Cross News Release, September 1, 2011 (http://newsroom.redcross.org/).

61. North Country Red Cross Fast Facts September 6, 2011 (http://newsroom.redcross.org/2011/09/06/fast-facts-hurricane-irene-red-cross-response-in-new-york/).

62. North Country Red Cross Fast Facts September 6, 2011 (http://newsroom.redcross.org/2011/09/06/fast-facts-hurricane-irene-red-cross-response-in-new-york/).

63. USGS/NOAA Lake Champlain Gage at Burlington, VT (http://waterdata.usgs.gov/vt/nwis/uv?site_no=04294500).

64. Luc Castonguay, Director of Urban Planning, St-Jean-Sur-Richelieu, QC "The City's Role in Managing the Flood-Prone Area" Presentation at LCBP's Flood Resilience Conference, June 2012.

65. Luc Castonguay, Director of Urban Planning, St-Jean-Sur-Richelieu, QC "The City's Role in Managing the Flood-Prone Area" Presentation at LCBP's Flood Resilience Conference, June 2012.

66. FEMA News Release Series DR-4020 and DR-4022 (https://www.fema.gov/disaster/4020/news; http://www.fema.gov/disaster/4022); Vermont Emergency Management.

67. USGS/NOAA Lake Champlain Gage at Rouses Point, NY (http://waterdata.usgs.gov/ny/nwis/uv?site_no=04295000).

68. NADO Research Foundation Center for Transportation Advancement and Regional Development with support from the Federal Highway Administration, VTRANS Irene Recovery Report, July 2012.

69. Andrew Kozlowski, New York state geologist via NPR 6/6/2011; NYS Division of Homeland Security (http://www.dhses.ny.gov/oem/mitigation/archive/documents/S3.J-Landslide-Hazard-Profile.pdf).

70. Neale Lunderville, Vermont Irene Recovery Report, January 2012 (http://www.vermontagriculture.com/news/2011/Irene_Recovery_Report_Jan_2012.pdf).

71. Neale Lunderville, Vermont Irene Recovery Report, January 2012 (http://www.vermontagriculture.com/news/2011/Irene_Recovery_Report_Jan_2012.pdf).

72. Vermont Emergency Management (http://vem.vermont.gov/), December 2012.

73. Vermont Emergency Management (http://vem.vermont.gov/), December 2012.

74. American Red Cross News Releases, September, 2011.

75. National Grid Upstate New York Press Release, September 1, 2011 (http://www.nationalgridus.com/aboutus/a3-1_news2.asp?document=6334). Accessed July, 2012.

76. VTrans (http://www.aot.state.vt.us/Irene/IreneTOC.htm) Accessed December 2012.

77. VTrans (http://www.aot.state.vt.us/Irene/IreneTOC.htm) Accessed December 2012.

78. VT ANR Irene Report, December 2011, http://www.anr.state.vt.us/anr/climatechange/irenebythenumbers.html.

79. FEMA News Release Series DR-4020 (https://www.fema.gov/disaster/4020/news).

80. T. Lavigne, Essex County (NY) Public Works Division, Personal Communication, May 4, 2012.

81. Rail Vermont (http://www.railvermont.org/tag/vran-news.html).

82. Parcs Canada (http://www.pc.gc.ca/lhn-nhs/qc/chambly/plan/inondations-flood.aspx).

83. NYS DEC (http://www.dec.ny.gov/outdoor).

84. NYS DEC (http://www.dec.ny.gov/outdoor).

85. Lake Champlain Ferries (http://www.ferries.com/). Accessed November, 2012.

86. NYS Canal Corps (http://www.canals.ny.gov/news/pressrel/2011/2011-04-29-canal-delay.html & http://www.canals.ny.gov/news/pressrel/2011/2011-05-27-weekend.html).

87. Parcs Canada (http://www.pc.gc.ca/lhn-nhs/qc/chambly/plan/inondations-flood.aspx).

88. Parcs Canada (http://www.pc.gc.ca/lhn-nhs/qc/chambly/plan/inondations-flood.aspx).

89. Jen Thalhauser, USACE Project Manager of the Waterbury Reservoir- personal communication.

90. Jen Thalhauser, USACE Project Manager of the Waterbury Reservoir- personal communication.

91. Wayne Graham, VT Rural Water, personal communication.

92. VT ANR Wastewater Management Division via ANR Irene by the Numbers Report, 2011.

93. Elizabeth Royer, VT Rural Water, personal communication; Essex County (NY) Office of Community Resources.

94. VT ANR Wastewater Management Division via VT ANR Irene Report, December 2011.

95. Tyler Whitcomb of F.W. Whitcomb Stone Quarry, Colchester, VT (September, 2012).

96. Vermont Emergency Management (http://vem.vermont.gov/), December 2012.

97. Essex County (NY) Emergency Management.

98. Sue Minter, Vermont Irene Recovery Officer, Keynote: 2011 Floods: Response, Recovery and Resilience at LCBP Flood Resilience Conference, June 2012.

99. NADO Research Foundation Center for Transportation Advancement and Regional Development with support from the Federal Highway Administration, VTRANS Irene Recovery Report, July 2012.

100. Québec Civil Protection (http://cdd.publicsafety.gc.ca). Accessed January, 2013.

101. FEMA Disaster Declaration DR-1995, June 15, 2011 (http://www.fema.gov/pdf/news/pda/1995.pdf).

102. FEMA Disaster Declaration DR-1993, June 10, 2011 (http://www.fema.gov/pdf/news/pda/1993.pdf).

103. City of Burlington Parks and Recreation (http://www.enjoyburlington.com/) Accessed July, 2012.

104. Community Sailing Center News Release (http://communitysailingcenter.org/lake-today/). Accessed July, 2012/.

105. Bob Elmy, owner of Whitehall Marina at Lock 12.

106. NYS Canal Corps.

107. Essex County (NY) Department of Tourism.

108. Christa Baertschi, owner of Camping-Plage Kirkland.

109. The Office of Governor Cuomo Press Release, September 19, 2011 (http://www.governor.ny.gov/press/09192011AdditionalAssistance). Accessed December 2012.

110. Québec Civil Protection.

111. Vermont Red Cross News Release, September 1, 2011 (http://newsroom.redcross.org/).

112. Vermont Red Cross News Release, September 1, 2011 (http://newsroom.redcross.org/).

113. North Country Red Cross Fast Facts September 6, 2011 (http://newsroom.redcross.org/2011/09/06/fast-facts-hurricane-irene-red-cross-response-in-new-york/).

114. North Country Red Cross Fast Facts September 6, 2011 (http://newsroom.redcross.org/2011/09/06/fast-facts-hurricane-irene-red-cross-response-in-new-york/).

Impact on Agriculture

Floodplains generally have very fertile and highly productive soil, making them ideal locations for agriculture. In the Lake Champlain Basin, much of the farmland is located within floodplains. As a consequence, floods heavily impact the agricultural sectors in Vermont, New York, and Québec. Though large portions of agricultural land in the Richelieu River Valley flood on a yearly basis, the widespread damage from the 2011 flood events was unprecedented. Furthermore, large volumes of agricultural runoff, including sediment and nutrients, contributed to the degradation of water quality in Lake Champlain.

Impact of Flooding on Agriculture

The 2011 flooding events impacted agricultural lands and the agriculture-related economy. Flooding both in the early spring and late summer shortened the growing season with a late start and an early end. Agricultural land, equipment, and farmsteads were damaged, reducing yields and elevating costs of production. Additionally, contaminated floodwaters and soils destroyed crops and livestock feed, heavily impacting revenue for the Basin's farmers.

Shortened Growing Season

In the early spring of 2011, land was flooded and soils were too saturated for planting in many parts of the Champlain Valley. The Intervale Community Farm in Burlington, Vermont is located in the flood zone of the Winooski River and was flooded during this time. The Intervale has sandy soils that are tolerant of wet conditions, allowing earlier plantings than most area farms. But in 2011, crops planted in the early spring were destroyed by heavy rains and flooding along the Winooski River. Due to water fluctuations, efforts to salvage crops between rain fall events were largely unsuccessful. At the end of the summer, the Intervale was again flooded by Tropical Storm Irene, leading to a partial early harvest and significant damage to produce that resulted in a loss of income for many farmers.

In Québec, agricultural production in the Richelieu River floodplain was equally impacted by spring flooding. At the peak of the spring floods in May and June, 170 farms and 6,177 acres (2,500 ha) in the upper Richelieu River Valley were affected. The reported damages were downgraded as the season progressed. On June 20, 2011, 117 farms accounted for 2,644 acres (1,070 ha) of unseeded land and 355 acres (155 ha) of damaged hay crops. Flooding due to Tropical Storm Irene was less severe in the Richelieu Valley, although high winds from the storm damaged several acres of cash crops.[115]

The shortened growing season impacted feed availability for livestock. In the Champlain Valley, the planting date for feed corn is usually late April, but was delayed until June. The Miner Institute, an agricultural research facility in northeastern New York, planted only 80 out of 300 acres (32 of 120 ha) of corn in the spring of 2011.[116] Flooding in Québec also affected dairy and other livestock productions through the loss of hay crops. Many of these farms were able to adapt their crops to the shortened growing season or purchase the necessary feed. A delay in corn production for livestock feed further delayed hay production later in the season. Consequently, feed and dairy product qualities were lower. For farmers who purchased feed, short supplies resulted in higher prices and decreased revenue for dairy and beef producers.

In Vermont and New York, Tropical Storm Irene impacted the second round of plantings and the end of summer harvest. Loss of corn, hay, and alfalfa crops put further stress on farmers relying on crops to feed livestock throughout the winter.

Damage to Agricultural Land and Farmsteads

During the spring floods and Tropical Storm Irene, farmers in the Lake Champlain Basin experienced major damages to their property from sedimentation, erosion, and contamination from floodwaters. Floodwaters oversaturated agricultural soils, making them unsuitable for crop growth by promoting fungal and stymieing root production. Flooded fields were often covered in thick layers of silt and rocks after the waters receded. Following Irene, farmers reported debris scattered throughout their fields including propane tanks, fragments of damaged buildings and trees. According to the USDA, over 9,000 acres (3,642 ha) of Vermont agricultural lands were affected by Irene.[117] In New York, the USDA paid $78.6 million in claims covering 225,000 acres (91,000 ha) of damaged farmland in New York statewide. In Québec, damages to farmland were equally observed. The Ministère de la Sécurité Publique (MSP or Ministry of Civil Protection) processed compensation claims related to debris removal, dike repairs, water pumping equipment and damages to culverts.

Production & Distribution

For the farms that were not directly impacted by flooding, damage to transportation infrastructure and road access limited the distribution of agricultural products, making it difficult for farmers to access customers. Immediately after Irene, 15 Vermont dairy farmers had to dispose of their milk because trucks could not access their property in time to haul it away without spoiling.[118] Farms, without power needed on-site electric generators to power their milking operations. Some dairy producers were forced to limit their milking to fewer cows to minimize stress on limited resources for generating power, and to reduce dairy production that could end up wasted by lack of distribution. For farmers in the Agri-mark Cabot cooperative, the cooperative covered the cost of the lost milk. The Fédération des Producteurs Laitiers du Québec (Milk Producers Alliance of Québec) had prepared an emergency plan in the event of milk not being able to be collected, but fortunately that plan was not needed. There was no interruption of milk collection on the affected dairy farms during the flooding in Québec.

Sedimentation & Top Soil

For farmers, soil is a valuable living resource that is built over time. Healthy top- soil can take years to develop, and careful operation to maintain. Irene, causing remarkable fluvial damage, washed away the top soil for many farms. The loss of several inches of valuable top soil can cost farms revenue from lost production and generation of new top soil may take several years.

Contamination of Crops

During both flood events, potentially contaminated floodwaters inundated or passed through the Basin's farmland carrying toxic debris. Since many crops and livestock production are intended primarily for human consumption, precautionary measures had to be taken. The FDA declared that any crops with an edible portion that came in contact with floodwaters were contaminated after inundation from flooding and had to be destroyed.[119]

Tropical Storm Irene – New York

Statewide in New York, 140,000 acres (56,650 ha) of agricultural land were destroyed by Tropical Storm Irene, much of it in the Hudson River Valley.[120] This figure is much larger than the 9,000 acres (3,600 ha) affected in Vermont, because the agricultural industry in the State of New York is more widespread and large-scale.[121]

Cornell Cooperative Extension warned farmers that the floodwaters, which washed over the late-summer crops, contained silt, but was also potentially contaminated with human waste and chemical pollutants.[122]

Tropical Storm Irene – Vermont

According to the USDA Farm Service Agency, 476 Vermont producers were impacted by Irene with economic loss to farmers at about $20 million.[123]

Damage to crops by acre, state-wide in Vermont:

- 6,065 acres of corn (2,450 ha)
- 225 acres of soybean (91 ha)
- 7,268 acres of hay (2,940 ha)
- 596 acres of fruit/vegetable (240 ha)
- 1,752 acres of pasture (709 ha)
- 1,402 acres of maple sugarbush (wind damaged; 567 ha)[124]

Due to the flash flooding from Irene in agricultural valleys, farmers were forced to destroy or not harvest edible crops intended for human consumption touched by floodwaters. Crops intended for livestock feed were closely monitored by state agencies to ensure safe levels of toxins were present in silage.[125] Estimated value of crop losses and crop land damage is greater than $10 million statewide according to the Vermont Agency of Agriculture.[126] Crops were damaged by flood inundation, erosion, and wind. Floodwaters that flowed over crop land left a thick layer of silt and gravel, smothering crops and leading to increased hillslope erosion on pasture lands. According to UVM Extension, Tropical Storm Irene had a much higher risk of crop contamination than the spring floods, due to more widespread reports of inundated waste-water treatment systems, septic tanks, and hazardous waste sites. In compliance with the Food, Drug and Cosmetic Act, the U.S. Food and Drug Administration and Vermont Agency of Agriculture prohibited the sale of all food that had been in contact with flood water. Consequently, $2 million in vegetable crops were not harvested or destroyed statewide in Vermont.[127] This estimate does not include the costs of lost feed, dairy, maple, and value-added agricultural products.

The effects of Tropical Storm Irene were less severe in the Richelieu River Valley. Minimal flooding was observed, however high winds did affect certain cash crops in the area effectively flattening the potential harvest.

Livestock and Livestock Feed

While there are reports in Vermont and New York statewide on livestock drowning or dying from illness caused by the floods, the major impact of the floods on livestock was indirectly through their feed. In Québec, the impact observed was almost exclusively related to feed damage. In the winter, farmers rely on forage and grains including corn, hay, and alfalfa to feed their livestock (primarily cows). Issues with feed began during the floods, when floodwater contaminated feed. Farmers were faced with the decision of using the potentially contaminated feed. Some hard-hit areas, such as farm fields along the Winooski River south of Montpelier, were forced to discard crops intended for livestock feed due to the high risk of heavy metal contamination. UVM Extension and the state agencies of agriculture tested feed supplies for mycotoxins (potentially produced by fungal growth), ash (from sediment), and heavy metals. Mycotoxins and heavy metals were at safe levels across most of the samples, though some samples exhibited spikes of heavy metal content after the flooding.[128] [129]State agencies monitored feed supplies for up to a year after flooding occurred in affected areas. Throughout the Basin, high levels of sediment were deposited on feed crops.

Normal levels of ash in silage are about 3–5.5% of the total mass, while the flood-damaged silage contained 4–22% ash.[130] The impact of high ash levels on cows is not well studied, but with high ash content it is likely the animals could consume excessive quantities of soil and sediment. To maintain a supply of feed throughout the winter of 2011–2012, some farmers diluted flooded forage with uncontaminated forage for feed.

Further damage to the feed supply due to wet conditions resulted in mold or poor silage fermentation. When silage is stored, oxygen levels impact the respiration process of the silage, thus impacting the levels of carbohydrates available in the feed. If oxygen is readily available, respiration uses up the carbohydrates, producing low quality feed. Fermentation can only occur once oxygen is depleted, as it lowers the pH so that mold and bacteria cannot survive. High moisture levels, promote mold growth and lead to poor fermentation in silage, thus reducing the value of the silage for feed.

With high water, pasture land for grazing livestock was limited. In Vermont alone, there were 1,752 acres (709 ha) of flood-damaged pasture land.[131] Moist soil promoted the growth of clostridia organisms and other pathogens that may cause diseases, abortion, or death of livestock. Many farmers were forced to limit grazing and closely monitor their herds.[132]

Local Food Sources

Local farms contribute fresh, local food and value-added products to the economy. Many farms in the Lake Champlain Basin distribute products to the consumer market through a food hub, a distributor or cooperative, and or at local farmers markets. The Intervale Community Farm, in Burlington, Vermont is an example of community supported agriculture that provides local food source. A primary source of upfront income is the investment of community members in community supported agriculture (CSA) also known as a “farm share.” This CSA usually produces a share with a 40-50% bonus over comparable retail prices, providing an incentive for community members to invest. The 2011 bonus was significantly reduced due to the spring floods. The flooding from Irene also destroyed many summer vegetables just before harvest. Similar problems occurred throughout the affected area. Summer crops, including carrots, onions, spinach, arugula, baby beets, winter squash and, pumpkins were inundated on nearly 200 farms in New York. Fresh produce from farms in Vermont and New York is supplied to urban areas, including New York City and Boston.

Impact of Agricultural Runoff on Waterways

Severe weather events cause flash flooding, significant runoff, fluvial damage to streambanks, and inundation, mobilize agricultural soils, along with fertilizers and pesticides that may be present in the soil. A consequence of agricultural runoff during flooding is intensified nutrient and sediment loading into the Basin’s waterways and to Lake Champlain.

Spring Lake Flooding
Photo: LCBP

Nutrient & Sediment Loading

About 90% of phosphorus loading is from non-point sources including stormwater and agricultural runoff in the Lake Champlain Basin. Agricultural runoff, rich in nutrients, carries high levels of phosphorus during flood events into Lake Champlain, its tributaries, and the upper Richelieu River Valley.

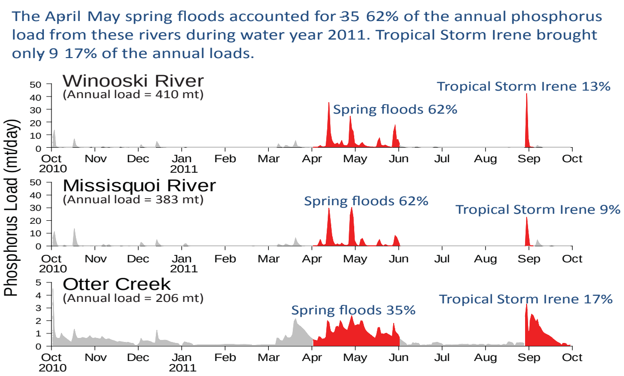


Figure 10. Phosphorus loading in 2011 in selected major Vermont tributaries.
Data courtesy: VT ANR

The impact of a flooding on agricultural runoff is highly dependent on timing of the event. During the spring 2011 events, most agricultural land was bare soil, and had been tilled and fertilized in preparation for planting. This increased sediment and nutrient loss through hillslope erosion. Rainwater and inundation mobilized soils containing cow manure or applied fertilizers. In the spring of 2011, the phosphorus load of the Winooski River totaled 77 metric tons in a single week, equal to half the usual annual load.[133] The Basin's waterways were milky brown, rich with sediment. The nutrient load introduced to the Lake may contribute to increased aquatic plant growth and persistent cyanobacteria blooms. The unprecedented sediment loading also changed the shallow benthic regions of the Lake, covering it with a muddy and rich depositional layer. In contrast, Tropical Storm Irene occurred in late summer when crops were well established, reducing the risk of erosion on the agricultural land, so most sediment loss and nutrient loading was associated with flash floods and fluvial damage to streambanks. Many rivers deposited enormous loads of nutrients and sediments into Lake Champlain after the flooding, particularly in the southern segments of the Lake. In several areas, however—notably in the Otter Creek watershed—flash floods inundated croplands and pastures in a broad floodplain, reducing the impact downstream.

Pesticide Loading

Pesticides, including herbicides, insecticides, and fungicides, are designed to kill or adversely affect nuisance species. According to Vermont Agency of Agriculture Foods and Markets, 76% of agricultural pesticide use in the region is herbicide for growing corn.[134] Agricultural operations spread pesticides over target areas, but also store pesticides for future uses. Storage of pesticides is regulated and required to be protected from unintentional release, including inundation by floodwaters. Flooding events increase the risk of moving applied pesticide residues into non-target areas through runoff. Mobilized pesticides may put surface drinking water supplies at risk, posing a potential threat to human health. After Irene, inundated crops were tested for pesticide contamination with only extremely low levels detected.[135]

Flood-contaminated pesticides that remain on premises may be rendered useless for agricultural use but could still dangerous for human contact, and thus may require professional disposal.[136] The disposal process presents further potential for environmental contamination. The Vermont Agency of Agriculture, Food, and Markets (VAAFM), New York State Department of Environmental Conservation Clean Sweep Program, and the Québec MDDEFP all have collection programs for the safe disposal of pesticides.

Existing Management

Because agriculture is such an important regional industry and local food resource in the Lake Champlain Basin and the Richelieu River Valley, it is important to maintain agricultural production while mitigating the impact of floods. Existing management includes local, state and federal programs that ensure farmers are economically supported during and after flood events.

State agricultural agencies in Vermont and New York regulate pesticides, livestock feed, seeds and fertilizers. VAAFM has specific water quality programs including the Accepted Agricultural Practices (AAPs), Medium Farm Operations (MFO), and Large Farm Operations (LFO) programs. In both states, agencies encourage Best Management Practices (BMPs) that mitigate agricultural impacts on water quality include reduced tillage, riparian buffers, wetland restoration or conversion, and surface drainage controls, among others. State agencies provide technical and financial assistance to farmers to implement BMPs to ensure compliance with current water quality standards. Many BMPs are voluntary except for Concentrated Animal Feeding Operations (CAFOs), which are mandatory, and many programs provide incentives for farmer implementation.

Agricultural Land in Floodplains

Most agricultural land in the Champlain Valley is located on or near a floodplain. Agriculture, specifically dairy and livestock production, is a major economic driver in the region. Best Management Practices (BMPs) are supported by state, federal and non-profit agencies, with incentives for the farmers to participate to reduce runoff to Lake Champlain from agricultural lands. Participating agencies include the Vermont Agency of Agriculture, Food and Markets (VAAFM), New York State Agency of Agriculture and Markets, regional agencies, the Québec Ministries of Sustainable Development, Environment, Wildlife and Parks, and Agriculture, Fisheries and Food, and the United States Department of Agriculture Natural Resources Conservation Service, non-profits and extension services by local universities. On many regional farms, efforts focus on reducing hillslope erosion, maintaining riparian buffers with livestock exclusion to streams, reducing tillage, properly managing nutrient runoff and other pollution prevention strategies. In times of flooding, these strategies help to reduce the impact on agricultural lands because high-impact areas near rivers and lakeshores are already protected by vegetated buffers. Farmers who do not comply with general Best Management Practices may be more at risk for flood damages.

When flooding occurs, farmers face the same economic hardships as businesses. Local non-profit organizations, federal and state agencies are available for immediate assistance. After Irene, the Vermont Agency of Agriculture, Food and Markets assembled a Rapid Assessment and Response team, connecting emergency responders, veterinarians, to farmers affected by the flood. Extension services provided by Cornell University and the University of Vermont lent technical assistance and supplies to flooded farmers. Federal programs immediately assessed damage to agricultural producers, determining the viability of crop production, insurance claims, and damage assessments. Long term financial assistance through a variety of organizations is made available to farmers before, during and after flooding disasters.

Damage to Feed Supplies

Flooded livestock feed supplies may be salvaged. State agencies have risk management protocols in place to protect farmers when production supplies may be contaminated by floodwaters. With proper management, risks associated with flood-damaged silage may be avoided. The current protocol states:

- Field Assessment/Risk Avoidance: Farms will be provided information to aid in the decision making process for harvesting flood damaged corn. The first priority will be field assessment to determine what fields or portions of fields can or should be harvested. Factors that will be considered in these assessments will be the physical condition of the stalks, inspection of the ears for mold, height of floodwaters and duration of flooding, amount of sediment on plants, and upstream potential hazards. The field assessment process will identify stands that should not be harvested, stands where chopper heads should be raised and stands that have not been impacted by floodwater.

- Risk Avoidance: Stands deemed unfit for harvest will be left in the field.

- Risk Management: Risk management practices will apply to harvested silage that has been exposed to floodwater but that has not been severely damaged. The issues associated with these crops will be primarily mycotoxin and pathogen contamination. Management activities for these risks include:
    - harvest at proper moisture content
    - segregation of flooded silage
    - inoculation or treatment of silage
    - pH management
    - moisture management in storage and proper ensiling techniques
    - sampling and analysis[137]

The state provided technical assistance and feed monitoring to affected farmers immediately after and for up to a year after flooding.

Testing for Contaminants

State agencies conducted post-flooding site inspections of the major agricultural pesticide applicator facilities in the affected areas. These facilities store and distribute commercial pesticides. Testing confirmed that none of the facilities were located in flood-damaged areas. Testing of forage crops was also completed by state agencies, and investigators concluded that crops flooded by Irene did not present a risk of pesticide contamination per FDA guidelines.[138]

State agencies conducted contaminant testing for feed crops, including corn and wheat, using existing federal protocols and baseline standards.[139] The primary crop of concern was corn for silage, and the primary contaminants of concern were heavy metals and mycotoxins. State agencies received guidance from the Federal Food and Drug Administration (FDA) to survey and monitor affected crops. Flood-damaged crops to be considered for livestock feed were tested for Mycotoxins, heavy metals, pathogenic bacteria, pesticides and PCBs. Testing for mycotoxins included, at minimum, aflatoxin, fumonisin, vomitoxin, zearlonone and ochratoxin. Heavy metal testing focused on cadmium, mercury and lead. Pathogenic bacteria of concern were *Salmonella*, E. *coli¸ Clostridium perfringens and botulinum.* All contaminant levels must be within the FDA guidelines for use in animal feed.[140]

The Vermont Agency of Agriculture, Food and Markets set up a three-tiered monitoring program to test for contaminants for a year after flooding occurred, selecting at-risk farms in floodways for participation. Tier 1 sampling was a broad-scale survey to determine baseline levels of heavy metal and mycotoxin contamination. Tier 2 determined the level of contamination in feeding materials using a sub-set of Tier 1 farms. Tier 3 analyzed milk from specific at-risk farms to determine additional management actions and risk mitigation.[141] Throughout the process, the Agency of Agriculture worked in cooperation with the Department of Environmental Conservation to monitor water quality. All flooded farms were eligible for risk management and technical assistance training. Producers regularly test for pathogens, mycotoxins, and ash. In the case of cash crops, a testing protocol has not yet been set up, so when floods occur, it is more difficult to interpret tests for pathogens. Any feed from a flood zone that entered the commercial market in 2012 could be subject to contaminant testing.[142]

Food Safety for Human Consumption

Generally, edible crops that are widely distributed are traceable to their source if a pathogen is discovered, but precautionary testing is not regulated. When widespread flooding occurs, inundated crops intended for human consumption are usually destroyed.

The Federal Food and Drug Administration policy states that any ready-to-eat crop inundated by flood waters is deemed unfit for human consumption. With prolonged flooding, the crops are also deemed unfit for livestock consumption as well.[143] A widespread flood event, like Tropical Storm Irene, increases the likelihood of contamination from sewage, septic, and hazardous waste, when inundated. Growers were required to destroy (or not harvest) edible crops that were in contact with floodwaters in any way, for any length of time. Food producers experienced a major loss due to this risk of potential contamination.

Soil Testing

The University of Vermont Agricultural Testing Lab provided free soil testing for flooded farm fields pairing samples from flooded and un-flooded fields, and testing for heavy metals and total petroleum hydrocarbon. Soils were tested for cadmium, copper, chromium, nickel, lead, and zinc. Of the 155 soil samples, there were no detections of elevated heavy metal levels.[144] Total petroleum hydrocarbon analysis was done to detect fossil fuels from gas, diesel, or oil in flood-contaminated waters. These tests only found expected background hydrocarbon levels, suggesting little contamination from floodwater. Testing soils for microbial contamination, such as E. *coli* and *Salmonella*, is costly. Microbial testing was not conducted for soils, because microbial pathogens are expected to decline over time, and human health risk is marginal when planting in the following spring. While the tests showed minor impact from contamination on agricultural soils, in the case of produce for human consumption and feed for livestock consumption, farmers must take the precautionary measure to avoid potential health risks from flooding. Soil analyses were not conducted in Québec as spring flooding is an annual event in the Richelieu Valley, although 2011 was unusually severe.

Financial Support for Farmers

Québec – Financial Assistance for Farmers

Following the severe flooding in May and June 2011, two financial support programs were put into place in order to help farms that were unable to seed agricultural land. The Montérégie-Ouest regional branch of Québec's Ministry of Agriculture, Fisheries, and Food (MAPAQ) administered both assistance programs for farmers. The overarching goal of the programs is to provide financial assistance for mitigating the impact of natural disasters, such as floods, to enable farmers to more quickly resume production.

First, a provincial government program entitled "Complimentary aid program for agricultural businesses affected by the Montérégie floods", funded entirely by the provincial government, provided $355 per hectare (1 ha=2.5 acres) of un-seeded land for the 107 farms affected by Champlain and Richelieu River flooding in 2011.

Secondly, Agriculture and Agri-Food Canada provide Business Risk Management (BRM) programs under the program *Growing Forward*, in which the federal agency works with the government of Québec Ministries to provide assistance to affected Canadian farmers on a disaster specific basis. The program offers a 60/40 cost share federal/provincial.[145] The provincial ministry (MAPAQ) administers the assistance, adding the federal funds to existing provincial assistance, to help producers at the local level.

In addition to the emergency financial assistance provided to affected farms, the Financière Agricole du Québec (FADQ) intervened with its crop insurance programs which it provides for certain sectors. The FADQ processed 87 insurance claims in the sector affected by flooding. Total compensation was $318,861.30 for 3,310 acres (1,339.4 ha).[146] The greater surface area addressed by the FADQ programs is due to compensations paid out for land that was intended for corn.

Vermont – Financial Assistance for Farmers

In Vermont, a variety of services were offered for farm recovery.[147] Vermont Agricultural Credit Corporation offered an emergency loan program for direct flood related damages and losses. Loans were offered at a 1% interest rate, and for the first two years no payments required; the maximum loan size was $100,000. The Vermont Farm Fund Emergency Loan offered $5,000 loans at 0% interest, payable over two years for farms in danger of shutting down business due to flooding. This program had a turnaround to approval of 14 business days. Also available to farmers, Farm First, offers short-term, free confidential counseling and resources for Vermont Dairy Farmers and their family members. The Vermont Agency of Agriculture partnered with the Vermont Community Foundation, creating the Vermont Farm Disaster Relief Fund, assisting Vermont farms damaged from Irene through donations, including a local Phish benefit concert. The Vermont Farm Disaster Relief Fund was able to provide 225 farmers with grants totaling over $2.4 million.[148]

New York – Financial Assistance for Farmers

Assistance to New York farmers from Tropical Storm Irene flooding came from a variety of sources. New York State Governor Cuomo's administration provided $15 million immediately.[149] Also, the Empire State Development Corporation (ESD) administered a program with the New York State Department of Environmental Conservation (NYS DEC) providing a total of $9 million for the Hurricane Irene-Tropical Storm Lee Flood Mitigation Program, with grants ranging from $300,000 to $500,000 per eligible county.

These grants support flood mitigation and control projects in streams impacted by Tropical Storms Irene and Lee. New York's Governor Cuomo later provided an additional $1.3 million in Agricultural and Community Recovery Fund grants to 143 farms in 21 counties to cover cost of livestock feed and damaged crops.

New York State Energy Resources and Development Authority established the Agriculture Disaster Energy Efficiency Program, providing funding for energy-efficient repairs and retrofits of damaged electric and natural gas agricultural producer equipment including milk processing, cooling, heating, and other farm systems.

United States Department of Agriculture, Farm Service Agency

The USDA Farm Service Agency provided Emergency Loans for farmers with physical losses or production shortfalls for the spring flooding (in Vermont) and Tropical Storm Irene. The Supplemental Revenue Assistance Payments Program assisting farmers by supplementing revenue lost from crop damage and quality losses.

Assistance programming from the USDA includes:

- Noninsured Crop Disaster Assistance Program (NAP): NAP provides financial assistance to producers affected by natural disasters. NAP covers non-insurable crop losses and planting prevented by disasters. Eligible crops include commercial crops produced for food or livestock feed, and specialty crops, such as maple syrup.

- Supplemental Revenue Assistance Payments Program (SURE): SURE was authorized by the 2008 Farm Bill and covers crop revenue losses from quantity or quality deficiencies only in declared disaster areas by the Agriculture Secretary or in cases where the overall production loss exceeds 50 percent.

- Emergency Assistance for Livestock, Honeybees, and Farm Raised Fish (ELAP): ELAP was authorized by the 2008 Farm Bill to provide emergency relief to producers of livestock, honeybees, and farm-raised fish and covers losses from disasters that are not adequately covered by other programs.

- Livestock Indemnity Program (LIP): LIP was authorized by the 2008 Farm Bill to provide assistance to livestock producers for livestock deaths from disaster events, in excess of normal mortality.[150]

Emergency farm loans allowing producers to borrow up to 100% of lost production or physical losses to a maximum of $500,000 also were available. Finally, the Emergency Conservation Program (ECP) provided emergency funding and technical assistance for farmers to rehabilitate flood-damaged farmland.

Management Needs

- Enhance emergency preparedness for agricultural businesses and farmers. Currently, the state agencies, University Extension services, USDA NRCS and the Farm Bureau are working together to create a comprehensive emergency preparedness checklist for farmers to ensure continuation of operations in the event of a natural disaster.

- Ensure communication between farms, businesses and agencies before, during and after flooding events. Some rural homesteads do not have internet or cellphone access. A communication network must be established to allow emergency response in rural areas.

- Encourage a Lake Champlain Basin-wide initiative by Vermont, New York, and Québec for farmers to allow agricultural land in floodplains to be flooded during storm events. Farmers could receive compensation or reach an agreement whereby they receive cost incentives if they maintain good riparian management practices to reduce the impact of future floods. The Prime Vert in Québec is an incentive program administered by the MAPAQ to help farmers and the agriculture sector adopt environmentally sound agricultural practices, improve water quality, and reduce greenhouse gas emissions. Some incentives exist for farmers to convert agricultural land bordering waterways into riparian buffers or wetland. The conversion of agricultural land into wetlands or riparian buffers mitigates the water quality impact of agricultural runoff by entrapping and retaining nutrients and sediments. This is very effective for flood mitigation, as the wetlands also are exceptional water storage resources, reducing the rate of a rising flood and effectively filtering many of the nutrients and sediments carried by the floodwaters. One common technique is the purchase of river corridor easements, compensating farmers for converting agriculturally productive land to mitigate flood risk.

- Reducing tillage can result in a 50%–63% reduction in agricultural runoff by keeping a groundcover on the soil in times when crops are not in production prior to, or after the growing season. Reduced tillage reduces the likelihood of soil erosion from stormwater by reducing the amount of exposed soil matrix, reducing agricultural runoff.

- Conversion of regularly tilled land into perennial crops is another option, in which the soil is continually protected from erosion by a groundcover. Perennial crops are generally grains or grasses.

- Water and Sediment Control Basins (WASCOBs) are agricultural runoff reduction structures being evaluated in the Lake Champlain Basin. It is a small basin designed to store and slow agricultural runoff, allowing sediment to settle from stormwater before it drains into a waterway. The LCBP is partnering with the State of Vermont to install and observe the effectiveness of WASCOBs in a pilot program.

- Create a comprehensive emergency response plan specific to the agricultural and rural communities who may easily be isolated during floods, including:
  - Refrigeration access/power supplies
  - Livestock management and evacuation
  - Immediate technical and financial assistance for at-risk farmers

Information Gap: Is there a quantifiable effect on water quality from increased flooding on agricultural lands?

Information Gaps and Data Needs

Information Gap: Which agricultural lands are located in high-risk floodplains?

Information Gap: What rural lands can be used for flood storage? Would storage of floodwater on agricultural land risk contaminating crops, soil, or water? What is the economic benefit of farm flood resilience?

Information Gap: What impact does the dike system in Québec have on flooding in agricultural areas?

Information Gap: What agencies are responsible for ensuring that large farming operations follow good flood management practices and have an emergency response system in place?

Data Needs:

- Determine the impacts of standard agricultural BMPs on reducing potential flood risk
- Quantify the downstream reduction of floods if all viable upstream floodplains areas were accessible, including agricultural fields and natural areas
- Improved sampling of contaminated crops as compared to un-flooded crops during future flood events, testing for microbial contamination, heavy metals, other common contaminants
- Evaluate the risk of feeding contaminated crops intended for human consumption to livestock
- Test remedial processes for utilizing flooded crops
- Critical source area evaluation of high-risk floodplains within agricultural areas.
- A Basin-wide hydrologic model that could help establish priority lands to be converted into wetlands and riparian buffers.
- Evaluate the risks of using agricultural land for floodwater storage. How much of a difference would storing floodwater on agricultural land make to mitigate flooding Basin-wide?
- Evaluate the influence of flooding on the dike system in Québec.

Some impacts of Tropical Storm Irene on Route 4 in Vermont. Photo: VT ANR

Endnotes

115. Carrolyn O'Grady, MAPAQ, personal communication, September, 2012.

116. The William H. Miner Agricultural Research Institute (NY).

117. VT ANR Irene Report, December 2011, http://www.anr.state.vt.us/anr/climatechange/irenebythenumbers.html.

118. Neale Lunderville, Vermont Irene Recovery Report, January 2012 (http://www.vermontagriculture.com/news/2011/Irene_Recovery_Report_Jan_2012.pdf).

119. Cary Giguere, Section Chief, VAAFM, personal communication, January 2013.

120. New York State Department of Agriculture & Markets.

121. Neale Lunderville, Vermont Irene Recovery Report, January 2012 (http://www.vermontagriculture.com/news/2011/Irene_Recovery_Report_Jan_2012.pdf).

122. Tracey H. Forfa, Deputy Director of the Center for Veterinary Medicine, FDA. Open Letter to Vermont Farmers for Inundated Crop Guidance; September 8, 2011.

123. USDA Farm Service Agency.

124. Neale Lunderville, Vermont Irene Recovery Report, January 2012 (http://www.vermontagriculture.com/news/2011/Irene_Recovery_Report_Jan_2012.pdf).

125. Cary Giguere, Section Chief, VAAFM, personal communication, January 2013.

126. Vern Grubinger, UVM Extension Report, "Impact of Irene on Vermont Agriculture", January 5 2012. 6pp.

127. Vern Grubinger, UVM Extension Report, "Impact of Irene on Vermont Agriculture", January 5 2012. 6pp.

128. Vern Grubinger, UVM Extension Report, "Impact of Irene on Vermont Agriculture", January 5 2012. 6pp.

129. Cary Giguere, Section Chief, VAAFM, personal communication, January 2013.

130. Vern Grubinger, UVM Extension Report, "Impact of Irene on Vermont Agriculture", January 5 2012. 6pp.

131. Vern Grubinger, UVM Extension Report, "Impact of Irene on Vermont Agriculture", January 5 2012. 6pp.

132. UVM Extension Flood Crops Fact Sheet "Managing Flood Damaged Crops and Forage from Tropical Storm Irene" September, 2011 (http://www.uvm.edu/extension/flooded_crops_factsheet_%20irene2011_uvmextension.pdf) Accessed January 2013.

133. Eric Smeltzer, Environmental Scientist, VT ANR. Presentation entitled "2011 Flood Impacts on Water Quality" at LCBP Flood Resilience Technical Workshop, February 2012.

134. Toxic Substance Management Strategy: Managing Toxic Contamination of Lake Champlain. Technical Report #69 Lake Champlain Basin Program Technical Advisory Committee, 2012, 28p.

135. Vern Grubinger, UVM Extension Report, "Impact of Irene on Vermont Agriculture", January 5 2012. 6pp.

136. Cary Giguere, Section Chief, VAAFM, personal communication, January 2013.

137. Cary Giguere, Section Chief, VAAFM, personal communication, January 2013.

138. VAAFM Flooded Feed Risk Mitigation Plan, Feed Monitoring and Survey Program 2011-2012.

139. Cary Giguere, Section Chief, VAAFM, personal communication, January 2013.

140. Tracey H. Forfa, Deputy Director of the Center for Veterinary Medicine, FDA. Open Letter to Vermont Farmers for Inundated Crop Guidance; September 8, 2011.

141. VAAFM Flooded Feed Risk Mitigation Plan, Feed Monitoring and Survey Program 2011-2012.

142. VAAFM Flooded Feed Risk Mitigation Plan, Feed Monitoring and Survey Program 2011-2012.

143. USDA/FDA joint Press Release, Sept 12, 2011 via Farm Service Agency.

144. Vern Grubinger, UVM Extension Report, "Impact of Irene on Vermont Agriculture", January 5 2012. 6p.

145. Agri-Food Canada AgriRecovery (www.agr.gc.ca). Accessed January 2013.

146. Carrolyn O'Grady, MAPAQ, personal communication, September, 2012.

147. UVM Extension Topical Storm Irene Assistance to Farmers Fact Sheet. September, 2011 (http://www.uvm.edu/extension/vacc_assistance_factsheet_sep2011.pdf). Accessed December, 2012.

148. Vermont Community Foundation, Farm Disaster Relief Fund (http://www.vtfloodresponse.org/IreneFunds/VTFarmDisasterReliefFund/tabid/184/Default.aspx). Accessed December, 2012.

149. The Office of Governor Cuomo Press Release, September 19, 2011 (http://www.governor.ny.gov/press/09192011AdditionalAssistance). Accessed December 2012.

150. United States Department of Agriculture.

Preparing for Future Floods

Policy and Management Recommendations

In conclusion, we recommend several policies that jurisdictions of the Lake Champlain Basin should consider to improve flood resilience. Some are only relevant to specific regions of the watershed; others could be enacted Basin-wide and beyond. The policies recommended below are not listed in prioritized order. To move forward, we strongly recommend that each jurisdiction (Vermont, Québec, and New York) create Flood Resilience Offices, Teams or Workgroups to coordinate resilience plans within each jurisdiction or region. It is important to remember that to protect human lives and infrastructure, as well as water quality and habitat, from flood events, an entire tributary network should addressed—from the small headwater streams to the main stem of the tributary and to the delivery point to receiving waters. During Tropical Storm Irene, much of the damage was caused by small tributaries overflowing and eroding their banks and culverts and sending debris downstream. Many of these recommendations apply directly toward management of the upper portion of the watershed, with the realization that containment of water there will reduce impacts downstream, and ultimately attenuate the rise in the level of Lake Champlain itself. Many federal, state, and provincial agencies already have access to resources needed to accomplish these policy recommendations. Natural disasters continue to cause loss of human life and substantial damage to public and private property, annually causing tens of billions of dollars in damage in North America.[151] Federal, state, and local governments, non-governmental organizations and the private sector must work together to identify alternative funding plans, including concepts such as a "flood resilience trading program" to implement strategies to reduce our vulnerability to weather events. Most jurisdictions in the Basin have policies in effect or in consideration that approach at least some of these concepts. Links to pertinent reference documents are provided in Appendix A; a summary list of existing policies in each jurisdiction is provided in Appendix B. The appendices provide information regarding which regulations, programs or reference documents are applicable to each jurisdiction.

There remains much concern about the effects of development around and structural modifications to the Chambly Canal system and the Richelieu River (the outlet of Lake Champlain), the effects of these modifications on the movement of water through this segment of the River, and the elevation of Lake Champlain during flood conditions. The International Joint Commission will be releasing a draft plan of study for an exhaustive review of this system to provide recommendations to the governments of Canada and the United States in a report to be issued in 2013. In view of this ongoing work, we do not report on or provide policy recommendations on this issue here.

1. Economic Impact and Justification for Flood Resilience

The floods of 2011 affected the economy of the Champlain Basin and Richelieu River Valley on many levels. Businesses were impacted, both negatively and positively, as people and businesses were displaced, and recovery efforts initiated. Relevant State and Provincial agencies should work to ensure that these economic impacts are appropriately documented, including lost revenues for businesses and agricultural operations, costs of public services, and the cost of rebuilding. Intrinsic costs that also should be assessed include psychological impacts, aesthetic and recreational impacts, and, of course, impacts to our water resources (WWTFs and drinking water suppliers). Finally, the costs of flooding to the services provided by the Basin ecosystem (and the corresponding benefits of those services) should be thoroughly documented and monetized, including costs to forest and aquatic habitats. Many natural resources and environmental conditions provided beneficial services during the 2011 flooding, minimizing damages and reducing costs of the events below what they otherwise might have been. These benefits often are not considered in economic assessments of natural disasters. One example is the role of the floodplains that Otter Creek was able to access between Rutland and Middlebury, VT during Tropical Storm Irene. The service this floodplain provided to the village of Middlebury by reducing the downstream discharge in the Otter Creek before the floodwaters arrived in Middlebury should be recognized, as should similar cases around the Lake Champlain Basin (Figure 8). Documenting the flood resilience benefits of the ecosystem services provided by floodplain forests and wetlands can help cultivate (or foster) the political willpower to conserve and restore these valuable parts of the Basin, and ultimately improve our resilience to future flood events.

2. Comprehensive Hydrological Model for Lake Champlain, Including Updated Flood Frequency Analyses to Support Flood Hazard Mapping

A hydrological model for Lake Champlain is critical to increasing flood resilience within the Basin. Knowledge of how water moves across the landscape, in quantities and rates, following precipitation events will provide a wealth of information for resource managers trying to fortify infrastructure, protect access to floodplain areas to reduce stream power, provide information on flow and flood frequency, and ultimately reduce fluctuations in the elevation of Lake Champlain and the Richelieu River. To complete this model, basic hydrologic data obtained pre- and post- flood events must be assessed. Consistent, long-term data sets must be maintained, including gauging of flows on the major tributaries of the Basin. This information is critical for hydrological modeling and flood frequency analysis. Climate data must be incorporated into this model to accurately predict responses in the Champlain and Richelieu watersheds to future weather patterns and storm events. Historical and predicted precipitation patterns and watershed responses will be key drivers to this model. Secondary benefits from a Basin-wide hydrological model will allow resource managers to predict nutrient and pollutant levels in surface water runoff after flood events, and the impact on the water quality of Lake Champlain.

Each jurisdiction should carefully review the most recent and reliable flood frequency data and ensure that flood return interval calculations are current. In view of increasing knowledge of climate change and improved topographic data for hazard area mapping, these reviews and recalculations will be more accurate and precise than previously possible, and so should be performed regularly and flood hazard maps kept up-to-date and accurate.

3. Identify Fluvial Erosion Hazard Areas

Fluvial Erosion Hazard (FEH) maps need to be developed and updated to identify and prioritize locations in river corridor floodplains most susceptible to damage from erosion during future flood events. In turn, local and regional development guidelines can be updated to encourage special floodplain protection districts for encouraging flood-resilient land uses, such as natural streamside buffers, country parks and certain agricultural practices. Existing jurisdictional policies can highlight the importance of identifying and protecting these zones using Best Management Practices (Appendix B). Local and regional planning documents also can identify ways to hold or slow stormwater runoff on the landscape by promoting low-impact development practices on municipal property and by encouraging landowners to implement these practices on their property as well. Additionally, the States and Province should engage property insurance companies with educational programs highlighting the risks of property development in floodplain areas. Recent studies by insurance companies have determined that weather-related loss events occur more frequently in North America than anywhere else in the world.[152]

4. Consistent Floodplain Development Standards

Floodplain policies governing development within the major flood zone (often interpreted as the 100-year floodplain) do not address risk of damage to properties outside, but adjacent to, this zone.[153] Extensive development immediately adjacent to the regulated 100-year floodplain could be at risk to events that are even minimally larger than 100-year event. In addition, regulations should address freeboard—the difference in elevation of a structure and the flood-stage elevation—restrictions on new structures to account for damage caused by wind-driven wave action at high Lake elevations. In the United States, most of the local communities that have adopted floodplain development standards have based them on the minimum standards municipalities must have in place to make their residents eligible for purchasing flood insurance through the National Flood Insurance Program (NFIP). Since these standards are designed mainly to reduce the costs of repairing flood damage to insured structures, they are not robust enough to protect floodplains from further encroachment. Instead, they allow significant development within mapped floodplains as long as new structures have a minimal degree of flood-proofing. A further challenge is that NFIP minimum standards address the risk of damage from inundation, but do not take into account the risk of damage from erosion, which is prevalent along high-gradient tributaries in the Lake Champlain Basin. A final challenge with these minimum standards is that they do not address risk of damage to properties outside but adjacent to the 100-year floodplain. Extensive development immediately adjacent to the regulated flood zone could still be at risk.

To address these challenges, floodplain policies—whether at the municipal, state or provincial level—should avoid new development (such as filling or construction of new structures) in undeveloped river corridors that are important for attenuating floodwaters and minimizing flood-related damage. It also may be important to consider limiting development within lands immediately outside the 100-year floodplain. Steps should be taken to ensure that floodplain policies and regulations will be consistently administered and enforced. In addition, all flood insurance programs should encourage flood-resilience practices for properties within the 500-year floodplain as there could be disproportionate damage during events that causes flooding in an area larger than the 100-year floodplain. Because of this, NFIP maps should include accurate, up-to-date 500-year flood zones. The strictest floodplain development standards that apply to river valleys also must be extended to lakeshores, in the case of Lake Champlain. In areas with a documented history of severe flooding, all new development within the 100-year flood zone should be prohibited.

5. Establishment of Lakeshore Protection Zones

LCBP recommends the establishment of "Lakeshore Protection Zones" Basin-wide. Substantial damage occurred along the shoreline of Lake Champlain during the Lake flood event in May 2011. Much of this damage occurred in places where "hard" structures such as seawalls had been installed along the shoreline or where the natural shoreline vegetation had been removed and planted with grass. Areas with intact vegetated shoreline zones, including full-sized trees and understory, suffered significantly less damage. To help mitigate the impacts of future flood events, development standards at the State, Provincial, and municipal levels should be enacted to protect these lakeshore zones, requiring maintenance of natural, mixed species vegetation where appropriate, and new development setbacks. To maximize the benefits of lakeshore protection zones for protecting water quality, ensuring bank stability, reducing flood damage, and protecting habitat, the size of these zones could be set based on two main criteria: 1) elevation (which determines how wide the area needs to be to ensure the safety of structures from inundation and wave damage); and 2) lakeshore slope (which determines how wide the area needs to ensure bank stability and infiltration of upland runoff). Based on numerous lakeshore studies of habitat and water quality, a minimum width of 100 feet (30 meters) from the edge of the mean high water level is often recommended. These studies also suggest that shoreland vegetation provides significant benefits for reducing flood damage when Lake levels are high.

6. Reduction in Bank Armoring

In some locations throughout the Lake Champlain Basin, armoring of tributary banks is still permitted with minimal oversight or permitting required, particularly on agricultural lands in river corridors. The negative effect bank armoring can have on the natural flow of a tributary system, by causing more erosional damage downstream of the armored area, is well established. LCBP recommends that bank armoring (lining the streambank with rip rap or other hard material) be prohibited regardless of the adjacent land use practices, including agriculture, except as a last resort measure to protect concentrated or essential developed areas or infrastructure, such as urban downtown areas or major travel corridors. Identification of these sensitive areas where channel management and bank armoring is acceptable could be an important component of resilient river corridor plans (consistent with the above recommendation).

7. Implementation, Enforcement and Public Acceptance of Floodplain Management Principles

Communities need to be engaged in and understand rationales for certain policies and regulatory approaches for improving flood resilience. The most effective approaches for increasing flood resilience include restricting filling and construction in floodplains through state or local development regulations (see #4 above), and conserving undeveloped floodplains that play a critical role in attenuating floodwaters and reducing downstream flood damage. Promulgating regulations to protect key areas of floodplains from development is an important first step, but such regulations will do little to build flood resilience if they are not consistently applied and enforced, and this in turn requires that they are well understood by the local or state officials responsible for issuing development permits.

Outreach programs should be developed to engage with local governing bodies and communities to help them understand why protecting floodplains is critical to increasing flood resilience in the Basin. Ideally, this would be accomplished through a Flood Resilience Office or Coordinator position presented as our final policy recommendation (15) in this report. The State Flood Resilience Offices or Flood Resilience Coordinator should work closely with local municipalities as well as Regional Planning Commissions (VT), Natural Resources Conservation Districts (VT), county government (NY), Soil & Water Conservation Districts (NY), and the local governing bodies within the Montérégie region of Québec to improve resilience efforts within the Basin.

8. Flood Resilience Tax Reductions for Lakeshore and Riparian Properties

Jurisdictions within the Lake Champlain Basin could modify existing property tax rules to provide incentives for lakeshore and river corridor property owners who are willing to develop and implement an approved Flood Resilience Plan for their property. This concept is loosely modeled on the existing Vermont Current Use program.

The criterion for eligibility could include:

- Owned shoreland or river corridor property in a zone that is at risk of erosion or inundation—perhaps the land would be identified on an NFIP, State, or Provincial flood hazard map to qualify; and

- Landowners would work with jurisdictions to develop an approved shoreland or river corridor conservation and flood resilience management plan; and

.

- Landowners would implement the conservation practices specified in the Flood Resilience Plan (such as maintaining a mix of woody vegetation on lakeshore properties or maintaining vegetated buffers and avoiding streambank armoring on river corridor properties). Consistent implementation of the plan would make the landowner eligible to receive a modest property taxation rebate for the property under the management plan.

The assessed value of enrolled properties would be contingent on a set "use value" rate and would follow a formula that is current for the jurisdiction; however, property owners implementing an approved Flood Resilience Plan would receive a defined rebate on property taxes, perhaps to be paid for by the general fund of each jurisdiction.

Such a program would not only advance flood resilience, it also would improve and protect water quality and riparian and shoreline habitat. The impact on government revenues from this program could be minimized by targeting only those property owners whose involvement and cooperation is most essential for achieving flood resilience. This concept could be explored in each jurisdiction, and adapted to fit with existing tax-related programs and regional stewardship needs for shorelands and riverbanks.

9. Promote Ecosystem Resilience

Floods are a natural part of the ecosystem. However, with climate change and human alterations to the landscape affecting natural flows and water levels, introduction of new species, and increases in nutrient loading to the tributary network and Lake ecosystems, flood events can have substantial impacts. Basic information is needed to fully assess these impacts,including identification of reference sites that have been minimally impacted by human influence and sites that have seen substantial human influence.

Canadian Army- Richelieu River, May 6 2011 Photo: QC MDDEFP

Keene Valley, NY post-Irene. Photo: SUNY Plattsburgh/Lake Champlain Research Institute

These sites should be located along the lakeshore and within tributary corridors in the watershed. Baseline mapping of these sites—including flora, fauna, and habitat conditions—should be performed so that future flood impacts can be better documented and evaluated. Understanding the impact of potential toxins and pollutants that may be transported by floodwaters to flora and fauna, and modeling of flood impacts on diversity, population patterns, and ecosystem health are all critical to fully assessing the impact that flood events can have on the Champlain ecosystem. Downstream invasion probabilities should be estimated, and the impacts of invasive species known to inhabit riparian corridors (such as Japanese knotweed or *Fallopia japonica*) should be documented. Relevant governing authorities (municipal, state, provincial, federal) should work in partnership to develop response plans.

10. Developing Risk Management Strategies for Wastewater Treatment Facilities, Public Water Supplies and Hazardous Waste Sites

Many wastewater treatment facilities (WWTFs) are located at the lowest elevation possible—closest to the Lake or tributary into which they discharge, placing these facilities at high exposure to flood events. Engineering design must incorporate floodplain standards, for example: tankage walls, electrical and stand-by generators and sludge drying beds must be located outside of the 100-year floodplain or be above the Base Flood Elevation (BFE); below-grade pumping stations must be flood-proof. However, these rules are not always uniformly applied. Drinking water supplies and hazardous waste sites would ideally be located outside of a flood zone, and must take precautions to reduce the impact of flooding. Each jurisdiction should work with municipalities to develop strategic Risk Management Plans for these facilities that will prevent damage from future flood events to minimize loss of treatment capacity and impacts to the delivery of potable water to communities in the supply network. Each jurisdiction should provide assistance to the municipalities to secure funding to implement these Risk Management Plans. Risk Management Plans should include plans for reconnection of water supplies in the event of an interruption in service caused by infrastructure damage or contamination. Municipalities should work with their respective jurisdiction to develop emergency spill response plans for toxic substances currently contained within their floodplain zones to ensure a swift response in the event that toxic substances are released into the environment during a flood event. Each Risk Management Plan should identify the floodplain for the facility or area of interest, critical or highly sensitive locations of the facility that need to be protected, and funding costs for improvements to the site or facility for flood-protection measures. Floodplain maps must be updated to best inform these risk management plans (Policy and Management recommendation #2).

11. Re-Assessment of Roads, Culverts, Bridges and Dams

Design standards must be established and manuals and permit requirements related to culvert and bridge design must be revised to address the likelihood of more intense and frequent storm events. This is necessary to avoid higher long-term maintenance, repair and replacement costs necessitated by flood damage.

Photo: SUNY Plattsburg/Lake Champlain Research Institute

It also helps to protect water quality and improve ecological connectivity of both aquatic and terrestrial species. In addition, FEMA reimbursement for properly designed and sized flood resilient infrastructure is contingent on clear and exact standards and regulations. Local standards in the United States should be closely coordinated with FEMA rules. Experience has clearly shown that spending a little extra money on stream culverts to design them to withstand higher stormflows can reduce the likelihood of failure during high-water events with secondary benefits of improving aquatic organism passage and reducing sediment accumulation and debris obstruction. Undersized culverts are more expensive to maintain, and more susceptible to washouts. Emergency repairs are substantially more expensive than scheduled maintenance and replacements. State, provincial, and municipal transportation officials should work together to: 1) inform, educate and train public works staff to develop flood-resilient standards and regulations; 2) identify at-risk culverts; and 3) implement other programs to support repairs and replacement structures adequate for future flood conditions. Similarly, bridges should be assessed for structural integrity and capability to withstand increasing flows of the tributaries that pass beneath them. Assessments of existing dams are critical to ensuring the safety of people downstream. Dams in the Basin should be inventoried, assessed, and prioritized for decommission to restore floodplain connectivity within the tributary system and reduce potential for flash floods during intense storm events. Recent research by the USGS has shown that Tropical Storm Lee (September 2011) caused enormous sediment and nutrient contamination downstream of dam structures in the Susquehanna River (Chesapeake Bay drainage) due to scouring of impounded sediments.[154] Roadways that parallel streambeds or that lie within river corridors also should be assessed for vulnerability during high-flow events, and if mitigation costs are too high or the risk of future road washouts is too great, relocation of the road away from the streambed should be considered as a viable alternative.

12. Improve Emergency Response Planning

The Lake and tributary flood events required similar, but somewhat different responses from emergency management agencies. The Lake flooding resulted in prolonged inundation of homes, primarily along the Richelieu River and, to a lesser extent, along the shores of Lake Champlain. This prolonged inundation caused substantial health risks as residents attempted to live with the flood, or returned too early to their homes after the floodwaters subsided. Emergency management agencies along the shore of Lake Champlain and the Richelieu River valley should develop evacuation plans for residents with homes at risk of inundation if the Lake elevation approaches flood stage. These flood response plans should account for relocation of evacuees into temporary housing with proper food and shelter for a minimum of 60 days if necessary. Emergency responses generated by the tributary flash flooding events require execution of Incident Command System protocols, particularly when communication and transportation infrastructure have been compromised. Within New York and Vermont, these protocols should be compliant with the National Incident Management System (NIMS) and associated employee training required. Municipalities in the Basin, in cooperation with State or Provincial Emergency Response agencies, should develop emergency response protocols that are focused around their tributary networks and their floodplains. Landowners and residents within floodplains should be made aware of the potential threats and dangers of adjacent tributaries, and be advised to develop their own evacuation plans should forecasted weather conditions merit such a response. Emergency response protocols also should contain short- and long-term recovery plans in the event of a major disaster affecting the region, beyond immediate crisis management.

13. Flood-Resilience Compensation from Insurance and Mortgage Lenders

Public and private insurance and mortgage lenders all assume some level of risk when insuring or lending money for property in a flood or erosion hazard zone. This risk should be considered when underwriting insurance or approving loans for new developments located within designated flood hazard zones; eligibility should be contingent upon appropriate flood-resilient practices as guided by jurisdictional standards established for this purpose. Currently, insurance premiums are based primarily on risk assessments, i.e. a new home that is built four feet (1.2 m) above the Base Flood Elevation (BFE) would pay less for insurance than the same home built at the BFE. Any non-compliant home should be denied flood insurance until they come into compliance.

14. Resilience in the Agricultural Community

Many farms were impacted by the multiple flood events in the Lake Champlain Basin in 2011. The spring flood inundated farm fields, delaying accessibility to fields and postponing planting of crops. Tropical Storm Irene damaged crops or washed them away entirely. Many issues arose for farmers during these events, including livestock management during the flash flooding of Irene, handling of pesticides, loss of power and refrigeration. Post-flood, testing for contamination of crops and proper disposal of hazardous materials also was a major concern. Federal, State and Provincial agricultural management agencies should work with farmers to develop a suite of guidelines for farms operating within either the Lake floodplain or near a tributary floodplain to reduce impacts of future flood events to daily farm operations and loss of income from compromised crops.

Flood resilience guidelines should incorporate information for available compensation programs —State, Provincial, and Federal—that farmers can access in the event of loss from a flood or other natural disaster. These guidelines also should provide recommendations to farmers regarding testing requirements for crops that have been inundated by floodwaters to help determine if crops are fit for use or sale, or if they need to be destroyed. Jurisdictions should work to develop their own flood response plans that incorporate provisions for sampling of contaminated crops to help provide guidance to producers in the short-term following a flood event. Jurisdictions also should develop policies to allow agricultural lands located in floodplains to be flooded during storm events, and to adjust agricultural drainage systems to increase storage of floodwaters, with compensation available to the producer for crops lost in return for the flood-mitigation service provided. Concurrently, these policies should mitigate flood impacts to water quality from agricultural lands.

15. Flood Resilience Office or Coordinator

The LCBP recommends the institution of a Flood Resilience Office for the State of Vermont, and for the Champlain-Adirondack Region of the State of New York, and a Flood Resilience Coordinator for the Missisquoi-Richelieu region of Québec. Each Office will operate within an appropriate jurisdictional body, and should be guided by an oversight committee representing the relevant governmental, public, business, academic or non-profit sectors, to ensure effective networking and to maintain continuity between transitions of leadership within governing administrations. This Office will coordinate flood resilience efforts throughout its assigned region, and work closely with federal and state, or provincial and municipal agencies, as well as regional and local governing bodies, to maintain a high level of communication among all emergency response and relief programs. The essential tasks are to optimize jurisdictional flood response and recovery during future flood events, and to facilitate communication and coordination across jurisdictions during and after flood events so as to optimize the deployment of information and resources that can support local disaster response, relief and recovery efforts.

The Flood Resilience Offices of the three jurisdictions also can promote discussion across the jurisdictions about ways of reducing the risk of flood damage from future flood events, for example through changes in floodplain development standards (see recommendation #4). The three offices should host training workshops within their specific regions on an annual basis, and foster communication among Resilience Coordinators in the Champlain Basin and surrounding regions to exchange ideas and information and help improve resilience in communities within shared watersheds. Training and informational workshops should be directed toward community and municipal leadership, transportation officials, and jurisdictional leadership. The Offices will assist municipalities with development of emergency preparedness, flood resilience and flood response plans to ensure that impacts on human life and environmental conditions are minimized during future flood events.

Venise-en-Québec May 6, 2011 Photo: QC MDDEFP

Endnotes

151. Guha-Sapir D, Vos F, Below R, with Ponserre S. Annual Disaster Statistical Review 2011: The Numbers and Trends. Brussels: CRED; 2012..

152. Munich R., 2012. Severe Weather in North America: Perils, Risks, Insurance. Executive Summary. 8 pp.

153. Patterson, L.A. and Doyle, M.W. 2009. Assessing effectiveness of national flood policy through spatio-temporal monitoring of socioeconomic exposure. J. American Water Resources Assoc. 45(1): pp. 237-252.

154. Hirsch, R.M. 2012. Flux of nitrogen, phosphorus, and suspended sediment from the Susquehanna River Basin to the Chesapeake Bay during Tropical Storm Lee, September 2011, as an indicator of the effects of reservoir sedimentation on water quality: U.S. Geological Survey Scientific Investigations Report 2012–5185, 17 pp..

Appendices

APPENDIX A: Partner Publications

Inondations printanières 2011 en montérégie - Aspects juridiques Barreau du Québec. Juin 2011.

Achieving lasting change in multi-organizational tasks: the case of flood warnings in Australia. John Handmer, Flood Hazard Research Centre, Middlesex University, Queensway, Enfield, EN3 4SF, UK , Chas Keys, State Emergency Service, Wollongong, New South Wales, Australia; Jim Elliott, Bureau of Meteorology, Melbourne, Australia. Received 14 January 1998; received in revised form 14 August 1998; accepted 1 September 1998.

Irene Recovery – Overview Sue Minter, Irene Recovery Officer November 28, 2012.

Community Recovery Partnership Report October 2012.

FDA Feed Crop Letter. Chuck Ross Secretary Agency of Agriculture, Food and Markets. October 2011.

FDA Vermont Crops Guidance. Tracey H. Forfa, J.D. Deputy Director, Center for Veterinary Medicine, Food and Drug Administration. September 8, 2011.

Impact of Irene on Vermont Agriculture. University of Vermont Extension. Compiled by Vern Grubinger, University of Vermont Extension, with assistance from: Heather Darby and Ginger Nickerson, University of Vermont Extension; Bob Paquin, Vermont Farm Service Agency; Chuck Ross, Vermont Agency of Agriculture; Pam Smith, University of Vermont Extension/USDA Risk Management Agency; and Gregg Stevens, NOFA-VT. January 5, 2012.

Service Assessment: Hurricane Irene, August 21–30, 2011. National Oceanic and Atmospheric Administration, Dr. Jane Lubchenco, Administrator. National Weather Service, Laura Furgione, Acting Assistant Administrator for Weather Services. September 2012.

Irene Biota.

Lessons Learned from Irene: Vermont RPCs Address Transportation System Recovery. NADO Research Foundation Center for Transportation Advancement and Regional Development with support from the Federal Highway Administration. July 2012.

After Irene: Adaptation, Policy, and Management, Middlebury College Environmental Studies Senior Seminar. Led by: Daniel Brayton & Diane Munroe. Spring 2012.

Recommendations to Improve the Strength and Resilience of the Empire State's Infrastructure. NYS 2100 Commission.

Operational early warning systems for water-related hazards in Europe. Lorenzo Alfieri, Peter Salamon, Jutta Thielen, European Commission - Joint Research Centre, Institute for Environment and Sustainability, via E. Fermi, 2749, 21027 Ispra (VA), Italy, Florian Pappenberger, Fredrik Wetterhall, European Centre for Medium Range Weather Forecasts, Shinfield Park, Reading RG2 9AX, UK. April 26, 2012.

Impacts to Stream Habitat and Wild Trout Populations in Vermont Following Tropical Storm Irene, Vermont Fish and Wildlife Department Annual Report.

Programme d'Aide Financière Spécifique Relatif aux inondations survenues du 10 Avril au 6 Mai 2011, dans des Municipalités du Québec.

VTR, GMRC & IreneVermont Rail System. Hurricane Irene Damage and Recovery Briefing Prepared for Vermont State House and Senate Transportation Committee. Montpelier, VT. October 12, 2011.

Reported Sewage Overflows by Facility since 2007. June 15, 2012.

VERMONT DR- 4022 ECONOMIC IMPACT ASSESSMENT ECONOMIC RECOVERY SUPPORT FUNCTION. U. S. Department of Commerce, Economic Development Administration. April 2012.

Vermont Recovering Stronger Irene Recovery Status Report. Presented to Governor Peter Shumlin. Sue Minter, Irene Recovery Officer. June 2012.

APPENDIX B: Existing Flood Policies in the Lake Champlain Basin

(policies amended as a result of the 2011 floods are included)

New York

New York Article 36 of the Environmental Conservation Law.

New York Part 503 of the New York State Register and Official Compilation of Codes, Rules and Regulations.

Proposed Legislation:

New York State Bill No. A00044 (2011). Enacts the New York state comprehensive flood mitigation grant act; appropriates $5,000,000 therefore.

New York State Bill No. A01442 (2011). Directs preparation of a flood response plan for the NYS canal system.

New York State Bill No A02762 (2011). Requires insurers insuring property in floodplains to include damages done by wave action or windblown waves and make available to all insureds who reside in single family homes in a floodplain homeowners insurance covering such damage.

New York State Bill No. A04526 (2011). Authorizes the commissioner of environmental conservation to establish a stream maintenance and flood control program; allows for the local governing body of a county to elect to pass a local law providing for a local option into such program; provides for the county to be responsible for performing the work outlined in an approved stream maintenance and flood control plan.

New York State Bill No. A04772 (2011). Relates to a program for flood damage to businesses; provides a tax credit for businesses that purchase flood insurance.

New York State Bill No. A08334 (2011).Enacts the flood assessment relief act of 2011 for the counties of Clinton, Essex, Franklin, Warren and Washington; holds school districts harmless.

New York State Bill No. A08648 (2011). Relates to payments of taxes in installments in certain school districts affected by floods or natural disasters.

New York State Bill No. A09106 (2011). Provides for grants to municipalities under the Hurricane Irene-Tropical Storm Lee Flood Recovery Grant program for lost tax revenue.

New York State Bill No. A09184 (2011). Authorizes municipalities to finance unanticipated flood-relief expenses incurred during the 2011 fiscal year.

Québec

Environment Quality Act (L.Q.E., c. Q-2, s. 2.1)

Regulation respecting the application of Environment Quality Act (R.R.Q., c. Q-2, r.3).

An Act Respecting Land use Planning and Development (L.R.Q., A-19.1).

Protection Policy for Lakeshores, Riverbanks, Littoral Zones and Floodplains Environment Quality Act (c. Q-2, r. 35).

Declaration of a special planning zone in the territory of the regional county municipalities of La Vallée-du-Richelieu, Haut-Richelieu, Brome-Missisquoi and Rouville (O.C. 964-2011, September 21, 2011).

Vermont

1. Act No. 91 (H.752) 2012. Conservation and development; water resources; stormwater; property conveyance --An act relating to permitting stormwater discharges in impaired watersheds.

2. Act No. 117 (H.577) 2012. Conservation and development; municipal government; public water systems; isolation distances for potable water supply and wastewater systems--An act relating to public water systems

3. Act No. 138 (S.202) 2012. Conservation and land development; water resources; flood hazard areas; stream alteration--An act relating to regulation of flood hazard areas, river corridors, and stream alteration.

4. Act No. 163 (S.183) 2012. Conservation and land development; potable water supplies--An act relating to the testing of potable water supplies.

5. Act No. 152 (H.464) 2012 .Conservation and development; natural gas and oil practices; water resources; hydraulic fracturing--An act relating to hydraulic fracturing wells for natural gas and oil production.

6. Act No. 37 (H.26) 2011. Conservation and development; water quality; fertilizer.

7. Act No. 141 (H.614) 2010 Agriculture; land use; composting.

8. Act No. 130 2010 (H.488) 2010, Fish; didymo; felt-soled boots and waders; prohibition.

9. Act No. 145 (H.779) 2010, Potable water supply and wastewater system permits; notification.

10. Act No. 117 (H.462) 2010, Public waters; docks and encroachments.

11. Act No. 110 (H.763) 2010, Water resources; water quality.

12. Act No. 41 (H.145) 2009, Agriculture; solid waste; composting.

13. Act No. 27 (H.80) 2009, Public water supply; water treatment.

14. Act No. 31 (H.447) 2009, Water resources; wetlands.

15. Act No. 46 (H.15) 2009, Water resources management; aquatic nuisance species.

2014: Revised Emergency Relief and Assistance Fund Rule.