

4-1: Inundation Flooding & Fluvial Erosion

Hazard Impacts	Probability	Potential Impact					Score:
		Infrastructure	Life	Economy	Environment	Average:	
Fluvial Erosion	4	4	3	4	4	3.75	15
Inundation Flooding	4	4	3	4	2	3.25	13

Score = Probability x Average Potential Impact

Flooding is the most common recurring hazard event in Vermont. In recent years, flood intensity and severity appear to be increasing. Flood damages are associated with inundation flooding and fluvial erosion. Data indicate that greater than 75 percent of flood damages in Vermont, measured in dollars, are associated with fluvial erosion¹ and not inundation. These events may result in widespread damage in major rivers' floodplains or localized flash flooding caused by unusually large rainstorms over a small area. The effects of both inundation flooding and fluvial erosion can be exacerbated by ice or debris dams, the failure of infrastructure (often as a result of undersized culverts), the failure of dams, continued encroachments in floodplains and river corridors, and the stream channelization required to protect those encroachments.

Inundation flooding is the rise of riverine or lake water levels, while **fluvial erosion** is streambed and streambank erosion associated with physical adjustment of stream channel dimensions (width and depth). Both inundation flooding and fluvial erosion occur naturally in stable, meandering rivers and typically occur as a result of any of the following, alone or in conjunction:

- **Rainfall:** significant precipitation from rainstorm, thunderstorm, or hurricane/tropical storm. Flash flooding can occur when a large amount of precipitation occurs over a short period of time.
- **Snowmelt:** melted runoff due to rapidly warming temperatures, often exacerbated by heavy rainfall. The quantity of water in the snowpack is based on snow depth and density.
- **Ice Jams:** a riverine back-up when flow is blocked by ice accumulation. Often due to warming temperatures and heavy rain, causing snow to melt rapidly and frozen rivers to swell.

Inundation and fluvial erosion may both increase in rate and intensity as a result of human alterations to a river, floodplain, or watershed. For instance, when a dam fails there may be significant, rapid inundation which can occur without warning. Public and private structures and infrastructure become vulnerable when they are located on lands susceptible to inundation and fluvial erosion.

Riverine Inundation Flooding:

The land area where inundation flooding occurs is known as the floodplain. During high water events, water flows out of the river bank and spreads out across its floodplain. FEMA defines the portion of the floodplain inundated by the 1% annual chance flood as the Special Flood Hazard Area (SFHA); the area where the National Flood Insurance Program (NFIP) floodplain management regulations must be enforced and where the mandatory purchase of flood insurance applies for federally secured loans.

Inundation flooding on larger rivers and streams typically occurs slowly, over an extended period of time but can spread out over a large area of land. Due to the slower onset of inundation flooding on larger rivers, there is time for

Table 23: National Weather Service Stream Gauge Status

	Major Flooding
	Moderate Flooding
	Minor Flooding
	Near Flood Stage
	No Flooding

1 <http://floodready.vermont.gov/RCFAQ#4>

emergency management planning (e.g. evacuations, electricity shut-off considerations, etc.) to take place. Though the inundation floodwaters are slower to hit, they often take time to recede as well, and exposure to water for an extended period of time can result in significant property damage. U.S. Geological Survey's (USGS) National Water Information System monitors real-time streamflow gaging stations in Vermont (Table 22).

In Vermont, most flood-related damage is due to fluvial erosion. Erosion occurs when the power of the flood (i.e., related to the depth and slope of the flow) exceeds the natural resistance of the river's bed and banks. Rivers that have been overly straightened or deepened may become highly erosive during floods, especially when the banks lack woody vegetation, or when the coarser river bed sediments have been removed. In areas where rivers are confined due to human activity and development, they have become steeper, straighter, and disconnected from their floodplains. The more trapped the river is, the greater power it will gain, which eventually results in a greater degree of damage to critical public infrastructure such as roads and stream-crossings, as well as homes, businesses, community buildings and other man-made structures built near rivers. Fluvial erosion is also increased downstream when all the eroded materials, i.e., sediment and debris, come to rest in a lower gradient reach, clog the channel, and cause the river to flow outside its banks. When severe enough, fluvial erosion can also be the cause of Landslides (see: Landslides). The land area that a river accesses to meander and overtop its banks to release flood energy without excessive erosion is known as the River Corridor.



Snowmobile bridge near Waterbury, VT flexes as debris and water rush past following Tropical Storm Irene
Photo Credit: www.mansfieldheliflight.com/flood

A river corridor includes the meander belt of a stream or river and a buffer of 50 feet. River Corridor as defined in Vermont statute is:

the land area adjacent to a river that is required to accommodate the dimensions, slope, planform, and buffer of the naturally stable channel and that is necessary for the natural maintenance or natural restoration of a dynamic equilibrium condition, as that term is defined in section 1422 of this title, and for minimization of fluvial erosion hazards, as delineated by the Agency of Natural Resources in accordance with river corridor protection procedures².

Vermont's River Corridor maps delineate river corridors for larger streams and rivers, and standard setbacks for smaller, upland streams. The setbacks were determined by factoring in the same stable stream slope requirements used when delineating a river corridor using a meander centerline setback. These maps are located on the Vermont FloodReady³ and Vermont Natural Resources Atlas⁴ websites.



Severe damage to Vermont Route 4 in Killington, VT due to fluvial erosion during Tropical Storm Irene
Photo Credit: www.mansfieldheliflight.com/flood

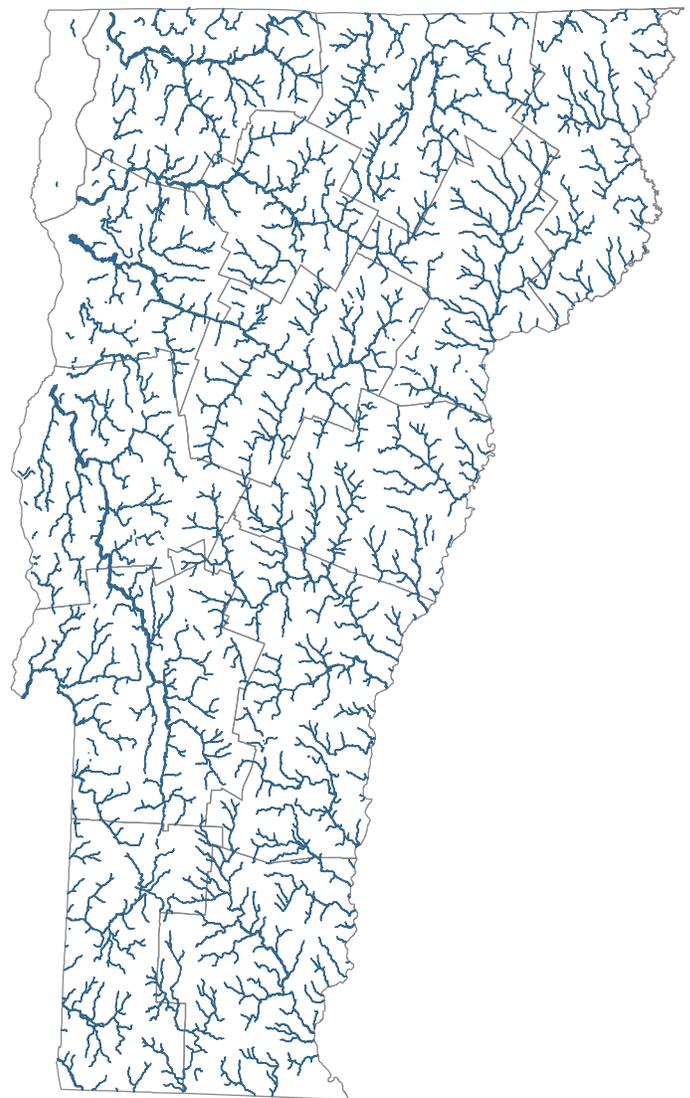


Figure 27: Vermont river corridor map (2015)
Data Source: <http://geodata.vermont.gov/>

2 <https://legislature.vermont.gov/statutes/section/10/032/00752>
3 http://floodready.vermont.gov/assessment/vt_floodready_atlas
4 <https://anrmaps.vermont.gov/websites/anra5/>

Channel adjustments with devastating consequences have frequently been documented wherein such adjustments are linked to historic channel management activities, floodplain encroachments, adjacent land use practices, and/or changes in watershed hydrology associated with conversion of land cover and drainage activities.

Vermont's landscape has historically contributed greatly to the widespread practice of the channelization of rivers and streams to maximize agricultural land uses and facilitate the development of transportation infrastructure. Channelization, in combination with widespread floodplain encroachment, has contributed significantly to the disconnection of as much as 70 percent of Vermont's rivers from their floodplains. In this unsustainable condition and when energized by flood events, catastrophic adjustments of the channel frequently occur, usually with consequent fluvial erosion damage to adjacent or nearby human investments.

Flash Flooding:

In addition to the inundation flooding and fluvial erosion dangers along rivers and lakes in Vermont, there are significant flash flood dangers near small streams and in alluvial fans. Alluvial fans are areas where streams transition between a steep mountain grade and gentler, flatter valleys below. Flash floods are likely to occur after a severe thunderstorm that produces a large amount of precipitation over a short amount of time. The precipitation falls so quickly that the soil is unable to absorb the water which results in surface runoff that collects in small, upstream tributaries, that then moves quickly downstream at a high velocity. The stream alterations described as increasing fluvial erosion may also exacerbate the effects of flash flooding. Mountainous areas such as Vermont are particularly prone to flash flooding due to the steep terrain. Damage from flooding includes land erosion, property damage, loss of crops, and even human life.

Floods are responsible for more deaths each year than any other hazard in the United States, with the majority being vehicle-related, as the power of moving water is usually underestimated. Flash floods have the power to knock a human off their feet with as little as six inches and move boulders, trees or even houses downstream. This mobile debris then can cause damage to infrastructure, plugging culverts or bridges, further exacerbating damage. Fortunately, in a flash flood, the water will recede but it can still cause damage to properties and structures.

The National Weather Service (NWS) issues a Flash Flood Warning when there is a rapid and extreme flow of high water into a normally dry area, or a rapid water level rise in a stream or creek above a predetermined flood level, beginning within a short timeframe from the onset of heavy rain, or from a dam or levee failure, or water released from an ice jam⁵.

Ice Jams:

Ice jams occur when warm temperatures and heavy rain cause snow to melt rapidly. Snowmelt combined with heavy rains can cause frozen rivers to swell, which breaks the ice layer on top of the river. The ice layer often breaks into large chunks, which float downstream and often pile up near narrow passages or other obstructions, such as bridges and dams. The water underneath the ice then looks for another means to pass, often resulting in road overtopping or damage to structures nearby.

Ice jams include those that form in the early winter as ice formation begins (freeze-up jams); those that form as a result of the breakup of ice covers (break-up jams); and those that contain elements of both (combination jams). Ice events can include ice jams, the formation of an ice cover that raises water levels upstream or decreases water levels downstream, or any other result of ice formation or break-up.

Vermont's northern latitude means a high likelihood of temperatures dropping sufficiently in the winter to allow freezing of most rivers. It is important to monitor the fluctuations on the State's rivers and potential for these events to occur with the thaws. Human settlement, development, and the associated infrastructure co-exist in proximity to rivers. Residences, buildings, or other infrastructure built within the floodplain will be susceptible to all flood types, including ice jams, especially as they have been identified as an increasingly dangerous hazard in Vermont.

The USACE CRREL in Hanover, New Hampshire, has compiled ice jam information on a regional and national basis⁶. When necessary, VEM and other State mitigation partners contact the nearby USACE office for additional data regarding ice jams. Between 1785 and 2017, there have been 987 ice jams on 102 rivers at 308 locations—ranking Vermont 10th in the country based on number of events (not including the early 2018 ice jams noted below).

Dam Failure:

While a rare occurrence, dam failure and resulting flooding can be devastating and threaten life and property downstream of dams. Dam failure can occur not only during large storms and high flows, but also during normal, sunny day conditions. While the depths and extents of flooding caused by dam failure are most severe during storms when reservoir elevations and rivers are at their highest, the public is generally conscience of flooding under these conditions. For this reason, it is often the sunny day failure scenario, that occurs with no warning, that is most dangerous.

Dam failure is caused by the overtopping or structural failure of a dam resulting in a significant, rapid release of water, which can lead to flooding. Structural failure can be caused by many factors, such as internal soil erosion in earth embankment dams, sliding or overturning of concrete dams, gate failure, or caused by other means, such as deliberate sabotage.

Dams are classified according to their potential for causing loss of life and property damage in the area downstream of the dam if it were to fail using the general classification system: High Hazard, Significant Hazard, and Low hazard. It is important to note that the hazard class is independent of the condition of a dam. Depending on the entity that regulates the dam, these definitions have minor but notable differences. In Vermont, dams are regulated by four distinct entities depending on the purpose and owner of the dam:

- Dams that are part of the production of power (i.e. hydropower) constructed before 1935 (with a few exceptions) are regulated by the State of Vermont Public Utility Commission (PUC). The PUC regulates approximately 25 dams, six of which are considered HIGH hazard and five of which are considered SIGNIFICANT hazard.
- Hydropower Dams constructed after 1935 (with a few exceptions) are regulated by the Federal Energy Regulatory Commission (FERC). FERC regulates approximately 80 dams, 18 of which are considered HIGH hazard and seven of which are considered SIGNIFICANT hazard.
- Dams owned by the Federal Government (i.e. United States Army Corps of Engineers, USACE) are essentially self-regulated by that agency. Federal entities regulate approximately 5 HIGH hazard dams and one SIGNIFICANT Hazard dam.
- Non-federal, non-power dams are regulated by the Department of Environmental Conservation, (DEC). The DEC regulates approximately 41 HIGH Hazard Dams and 110 SIGNIFICANT hazard dams.

6 <http://icejams.crrel.usace.army.mil/apex/f?p=524:1>

Table 24: Dam Hazard Classification - PUC and DEC Regulated Dams

Hazard Category	Potential Loss of Life	Potential Economic Loss
High	More than a few	Excessive (Extensive community, industry or agriculture)
Significant	Few	Appreciable (Notable agriculture, industry or structures)
Low	None expected	Minimal (Undeveloped to occasional structures or agriculture)

The classification systems for FERC and Federally-regulated dams are similar to that above, with the exception that for the SIGNIFICANT hazard classification, their definition indicates no probable loss of human life, but economic loss, environmental damage, disruption of lifeline facilities, and impact to other concerns is anticipated. The difference in life safety relative to the SIGNIFICANT hazard classification should be noted.

The following table provides the general, targeted inspection schedule for formal inspections at dams based on the regulating body in Vermont. In general, the depth and extent of inspections vary based on the timing, condition, and risk associated with the dam being inspected.

Table 25: Dam Inspection Schedule - PUC and DEC Regulated Dams

Hazard Category	DEC*	PUC	FERC	Federal
High	Yearly	Every 5 years	Yearly	Yearly
Significant	Every 3 to 5 years	Every 10 years	Yearly	Yearly, Varies
Low	Every 5 to 10 years	None required	Every 3 years	Varies

*The DEC inspection program is currently voluntary and requires permission of the dam owner.

Emergency Action Plans (EAPs) are pre-arranged plans developed by dam owners and emergency responders that serve to safeguard life and property in the event of a dam failure. General components of EAPs include: guidance for emergency detection and classification, notification flow charts, responsibilities and preparedness, and flood inundation maps, which are maps that depict the estimated extent, depth, and velocity of floods caused by simulated dam failures. The abovementioned regulatory agencies in Vermont generally require EAPs and are working towards EAP compliance.

The DEC is coordinating efforts to complete emergency action plans (EAPs) for all significant and high hazard dams within their jurisdiction, generally completing several per year funded through a dam safety grant from FEMA. Nearly all of the high hazard dams in DEC's jurisdiction currently have EAPs, but many are out of date. The Dam Safety Program is also in the process of developing new dam breach analyses,

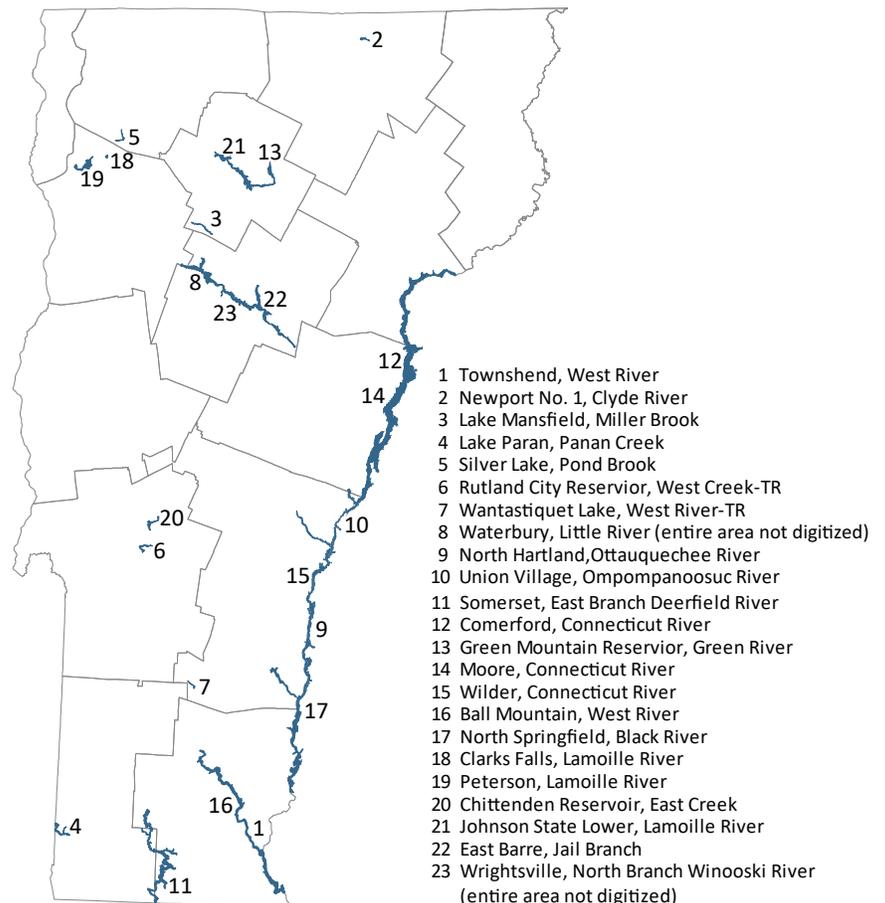


Figure 28: Vermont high-risk dam inundation areas for which there is full or partial* inundation mapping available (*Little River and Wrightsville)

Inundation maps do not account for compounding impacts.

Data Source: <http://geodata.vermont.gov/>

flood mapping, and EAPs for the three Winooski River Flood Control Dams (Waterbury, Wrightsville and East Barre), which are large, high hazard dams owned by the State.

In 2018, the Vermont State Legislature passed a law updating the existing “regulation of dams” statute 10 V.S.A. Chapter 43 that applies to the DEC and PUC. The purpose of the law is to serve to protect public safety and provide for the public good through the inventory, inspection, and evaluation of dams in the State. The law aims to provide a definition for a dam, update and modernize the State’s dam inventory and give the DEC rulemaking authority for items such as exemptions, registration, hazard classifications, EAPs, inspections and design standards. These rules will be developed over the next several years.

Lake Inundation Flooding & Erosion:

The Lake Champlain Basin has a relatively wet climate, averaging approximately 37.5 inches of precipitation on an annual basis. As the topography within the basin is comprised of steep mountain slopes and narrow river valleys, floodwaters have access to very little flat area to spread out across and on which to be absorbed, leaving much of the excess water to be funneled directly towards Lake Champlain. The lake is considered to be at flood level once the elevation tops over 100 feet above sea level⁷. FEMA’s Base Flood Elevation (BFE) of Lake Champlain is 102 feet. The highest recorded level at the gage in Burlington was 103.27 feet on May 6, 2011. Overall, 2011 was a record breaking year for Lake Champlain water levels in May and September, as illustrated in the chart below showing the max recorded lake level throughout the year with the 2011 lake level. It is worth noting that the published BFE and 2011 flood levels shown below are stillwater elevations and do not consider wave action. In 2011, wave action increased flood levels an additional three to five feet, depending location, causing significant flood damage for lakeshore property owners.

Major Flood Stage:	101.5'
Moderate Flood Stage:	101'
Flood Stage:	100'
Action Stage:	99.9'

Lake Champlain Water Level—2011 Level & Summary Level Through 2017

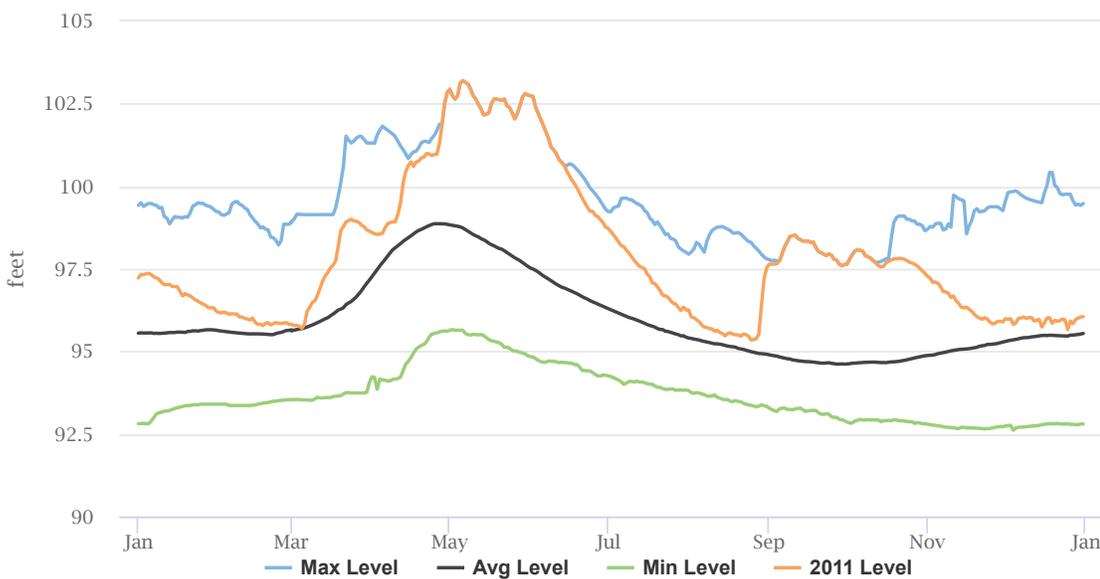


Figure 29: Lake Champlain water level—2011 level and summary level through 2017
 Source: <https://www.weather.gov/btv/lakeLevel?year=2011>

7 <http://www.lcbp.org/water-environment/water-quality/flooding/>

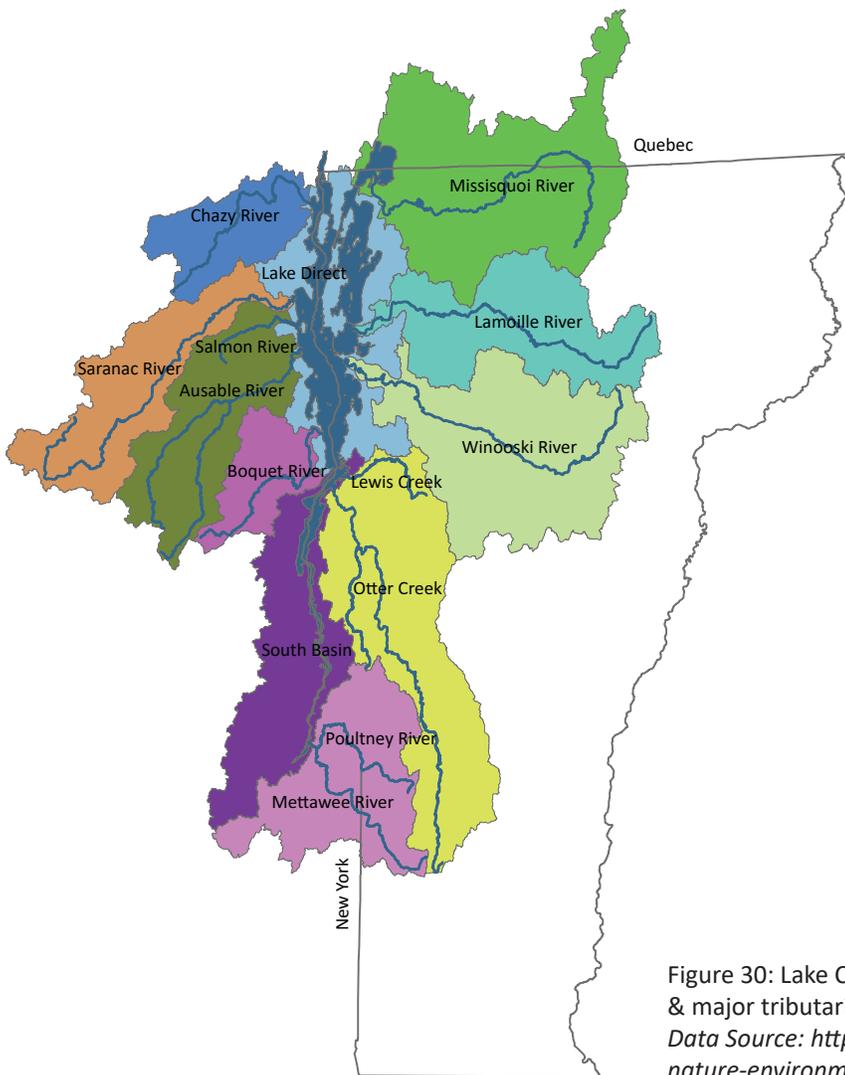


Figure 30: Lake Champlain sub-basins & major tributaries map
 Data Source: <http://atlas.lcbp.org/nature-environment/lake-champlain/>

Inundation - Fluvial Erosion History

- **Rainfall Event, November 3, 1927:** This event was caused by nearly 10" of heavy rain from the remnants of a tropical storm that fell on frozen ground. The flood claimed 84 lives, more than 1,000 bridges, and hundreds of miles railroads and roads. Over 600 farms and businesses were destroyed. Flooding in the White River valley was particularly violent, with the river flowing at an estimated 120,000 cubic feet per second on the morning of the November 4, 1927.
- **Rainfall & Snowmelt Event, March 13–19, 1936:** historic flood damage in Vermont occurred in the hamlet of Gaysville, which had a large mill, church, stores, and many residences destroyed during the flood. The worst widespread spring flooding occurred on, when slow-moving storms with warm air combined to drop around 8" of rain on a late winter snow pack that had a water equivalent of 10".
- **Rainfall Event, September 21, 1938:** a very fast-moving hurricane (known as the "Long Island Express") hit Vermont in the early evening causing severe flooding as a result of more than 4" of rain that accompanied the storm. Buildings were lost, power lines downed, and many trees felled.
- **Rainfall Event, June 28-30, 1973:** widespread flood when up to 6" of rain fell. A Presidential disaster was declared for the entire State and damage was estimated at \$64 million (in 1973 dollars).
- **Rainfall Event, August 9-10, 1976 (DR-518):** remnants of Hurricane Belle caused significant rain and flooding in portions of Vermont, resulting in \$100 million in damages (in 1976 dollars) and 10 associated deaths⁸.

8 http://www.trorc.org/wp/wp-content/uploads/2013/08/Appendix_I_Flood-Events-in-the-past-100-years.pdf

- **Ice Jam, Montpelier, March 11, 1992 (DR-938):** approximated a 100-year event. It resulted in nearly \$5 million (nominal dollars) in damages to local roads, buildings, private businesses, and homes. This disaster effectively shut down many functions of state government and the state legislature for several days, resulting in indirect losses for which no existing data has been generated. The inundation associated with this jam was of very short duration (less than 12 hours); otherwise, disruption of services could have represented a much more serious economic loss.
- **Rainfall Event, June 17–August 17, 1998 (DR-1228):** intense summer thunderstorms flood when torrential rain deluged the Warren, Randolph, and Bradford areas. A record amount of precipitation fell in Vermont that summer, with Burlington setting a new annual rainfall record of 50.42”.
- **Rainfall from Tropical Storm Floyd, September 16, 1999 (DR-1307):** caused flooding and wind damage in parts of Vermont.
- **Rainfall Flash Flood Event, July 14-16, 2000 (DR-1336):** 2-4” of widespread rain fell, with locally higher amounts across higher terrain. Specific amounts included 3” in Bennington and 5” in Wardsboro. This rain produced enough runoff to cause the Battenkill to exceed the 6’ flood stage by about a foot at Arlington. The Deerfield River rose 6’ above unofficial flood stage in Wilmington. Several roads were reported under water. Thunderstorm rainfall, as well as the earlier rainstorm, dumped in excess of 8” in Newfane. In Shaftsbury, County Route 67 was washed out. U.S. Route 7 was closed due to flooding and rockslides. In Windham County, a five-mile stretch of State Route 30 was closed due to flooding and residents were evacuated. Street flooding was reported at Brattleboro.
- **Snowmelt, December 16-18, 2000 (DR-1358):** Despite the fact that DR-1358 (2000) is officially listed as a winter storm, and DR-1101 (1996) occurred in January, damages in both cases were primarily flood-related, particularly for DR-1101, which was flooding associated with rain and a mid-winter thaw that melted a 30” snow pack in two and a half days.
- **Rainfall Flash Flood Event, July 24-August 13, 2003 (DR-1488):** July 24 saw steady rain during the morning hours, with locally heavy rain associated with thunderstorms later in the day. Scattered showers and thunderstorms erupted during the afternoon hours on August 3. A slow moving storm over Windham County produced estimated rainfalls of 3- 4” in about four hours, causing flash flooding. Around \$1 million in estimated damages.
- **Rainfall Event, August 12, 2004 (DR-1559):** A frontal boundary from northern Vermont southwest across eastern New York resulted in showers and thunderstorms with very heavy rainfall. Flash flooding in Addison County on August 28 resulted in nearly \$2 million of estimated damages due to thunderstorms accompanied by torrential rainfall with 2-5” of rainfall falling on already saturated soil. Numerous smaller roads were flooded or washed out, many homes reported flooded basements.
- **Rainfall Flash Flood Event, May 19, 2006:** In May 2006, Burlington received a record amount of rainfall, almost an inch more than the previous record, set in 1983. Rainfall amounts included: the NWS Burlington office in South Burlington with 3.48”, Jericho at 3.75” and Mount Mansfield with 4.79”.
- **Rainfall Flash Flood Event, June 26, 2006:** Flooding caused extensive damage to the small town of Athens, Vermont. This flooding was caused by persistent rainfall for the entire month of June, exacerbated by excessive rain caused by one storm system passing through. The damage was mostly suffered in roadways because of flash flooding, which turned a normally placid body of water, Bull Creek, into a raging flow. There were reports of a mudslide in Dummerston, which also caused damage to roadways. The State Emergency Operations Center (SEOC) was activated.
- **Ice Jam, March 15, 2007:** Montpelier experienced a significant ice jam event on the Dog River, resulting in extensive planning and preparations for possible flooding. A significant ice jam had been in place on the Winooski in Montpelier since January 20th, causing the Dog River jam. In early 2007, ice jams also caused problems in the towns of Woodstock and Chelsea, including localized road flooding in some locations.

- **Rainfall Event, July 9, 2007 (DR-1715):** Localized heavy rainfall exceeded 3” within two hours with some localized storm totals approaching 6”, causing many roads to be flooding or washed out and an estimated \$4 million of property damage.
- **Rainfall Flash Flood Event, June 14, 2008 (DR-1778):** Localized heavy rainfall up to 7” occurred in Ripton (Addison county) and 3-5” in Rutland (Rutland county) with an estimated \$2 million worth of damage in Rutland County, predominately in downtown Rutland.
- **Rainfall Event, July 24, 2008 (DR-1790):** Widespread rainfall of 1-2” occurred during the afternoon and evening of July 24th with localized amounts that exceeded 3”, causing flooding in Washington, Lamoille, Orleans and Caledonia counties.
- **Ice Jams, January 25-February 1, 2010:** ice jams were reported in Montpelier, Ferrisburg, Shelburne, Berkshire and Stratford, accompanied by minor localized flooding in some locations.
- **Ice Jam, March 6, 2011:** an ice jam formed on the Mad River caused damage to roads and threatened flooding to the area near Moretown and several other towns following heavy rainfall on March 5-6.
- **Snowmelt & Rainfall Events, April and May, 2011 (DR-1995, DR-4043):** 2011 was a record year for flooding in the State of Vermont. A total of four disaster declarations were issued, all attributed to flooding and fluvial erosion. The first floods occurred over a two-week period in April and May. These floods impacted the northern half of the state, including the counties of Addison, Chittenden, Essex, Franklin, Grand Isle, Lamoille, Orleans, Washington, and Windham. The damage totaled over \$1.8 million in FEMA assistance. In the spring, heavy rains in late March/early April on top of a deep late season snowpack resulted in riverine flooding and sent Lake Champlain well over the 500-year flood elevation. Additional spring runoff events resulted in Lake Champlain being above base flood elevation for more than a month. High lake levels coupled with wind driven waves in excess of 3 feet resulted in major flood damages for shoreline communities. May 6, 2011 was the highest ever recorded level of Lake Champlain in Burlington at 103.27 feet, one of only two recorded levels above major flood state (101.5ft).
- **Snowmelt & Rainfall Event, May 26, 2011 (DR-4001):** although not as severe as floods that occurred earlier in the month, multiple counties were included in the declaration, including Caledonia, Essex, Orange, and Washington counties. The river gage on the Winooski in Montpelier crested at 19.05 feet (major flood stage is 17.5 feet), the second highest on record (1927 flood: 27.10 feet).
- **Rainfall from Tropical Storm Irene, August 28, 2011 (DR-4022):** severe damage statewide from record-breaking rainfall associated with Tropical Storm Irene. The storm impacted the entire State, with Public Assistance designations for every county and Individual Assistance designations for 12 of 14 counties. The highest recorded rainfall during this event was on Mendon Mountain, totaling over 11”, making it the greatest single-day rainfall in Vermont’s recorded history. Given the significance of this event on the State, more details are below.
- **Rainfall Flash Flood Event, May 29, 2012 (DR-4066):** severe storms, tornadoes, and flooding occurred on May 29, 2012, impacting Addison, Lamoille, and Orleans counties. Over \$1 million worth of damages estimated. Some of these thunderstorms deposited up to 2” of rainfall in portions of north-central and northeast Vermont. The end result was flash flooding in portions of north-central, northeast Vermont and Addison county with estimated storm totals of 3-5”.
- **Rainfall Flash Flood Event, May 22, 2013 (DR-4120):** heavy rain event caused flash flooding, predominately in Chittenden County, washing out bridges, culverts, and roads. Over \$2 million worth of damages estimated.
- **Rainfall Flash Flood Event, June 25-July 10, 2013 (DR-4140):** thunderstorms produced a quick 1-3” of heavy rain in a half hour, causing flash flooding across the State, with over \$6 million worth of damages estimated. The most significant impacts were in Windsor and Chittenden Counties.
- **Snowmelt & Rainfall Event, April 15, 2014 (DR-4178):** a combination of heavy rain and snowmelt from late-season snowpack caused flooding across northern and central Vermont with nearly \$2 million in estimated damages. 4-6” was released from the snowpack.

- **Rainfall Flash Flood Event, June 11, 2015 (DR-4232):** thunderstorms with 1-2” of heavy rainfall caused flash flooding in Chittenden and Washington Counties with over \$1 million in damages.
- **Rainfall Flash Flood Event, June 29-July 1, 2017 (DR-4330):** heavy rainfall of 3-4” over several days caused pre-saturated soils across much of central Vermont. During the afternoon of July 1st, a series of heavy rain showers and thunderstorms moved in delivering very heavy localized rainfall that caused some scattered flash flooding, with an estimated over \$8 million in damages.
- **Ice Jam, January 13, 2018:** Swanton and Johnson as well as several smaller jams across Vermont.

Tropical Storm Irene, August 28, 2011 (DR-4022), Continued:

Inundation flooding and fluvial erosion caused by Tropical Storm Irene was catastrophic, destroying property, infrastructure and taking lives.

After a very wet spring, which lead to multiple disaster declarations and saturated soils, Vermonters watched Hurricane Irene move up the Eastern Seaboard of the United States with great apprehension. The hurricane turned into a tropical storm as it made landfall in New York and Connecticut, shortly before moving northward towards Vermont. As the tropical storm moved into the State, dropping as much as 11” of rain, nearly every river and stream flooded and experienced catastrophic fluvial erosion. Extensive transportation damage was reported, with nearly every State highway affected and many local roads washed away. In Vermont, seven people died and many were injured from the floods.

During Tropical Storm Irene, flooding originated in headwater streams draining the flanks of the Green Mountains, where rainfall totals were highest. As these high-gradient headwater streams filled quickly, the water rushed down the hillsides and inundated the narrow valleys. These high-gradient streams with minimal floodplain attenuation rose and peaked rapidly in a matter of a few hours, and then receded nearly as quickly. By contrast, larger rivers of lower gradient with wide floodplains and contiguous wetlands were able to attenuate the storm flows. Accordingly, these rivers peaked later and receded more slowly.

Below is a brief look at some of the effects of Tropical Storm Irene, according to the Agency of Natural Resources, which explains the impacts from this particular event and highlights how Vermont is vulnerable during a significant precipitation event.

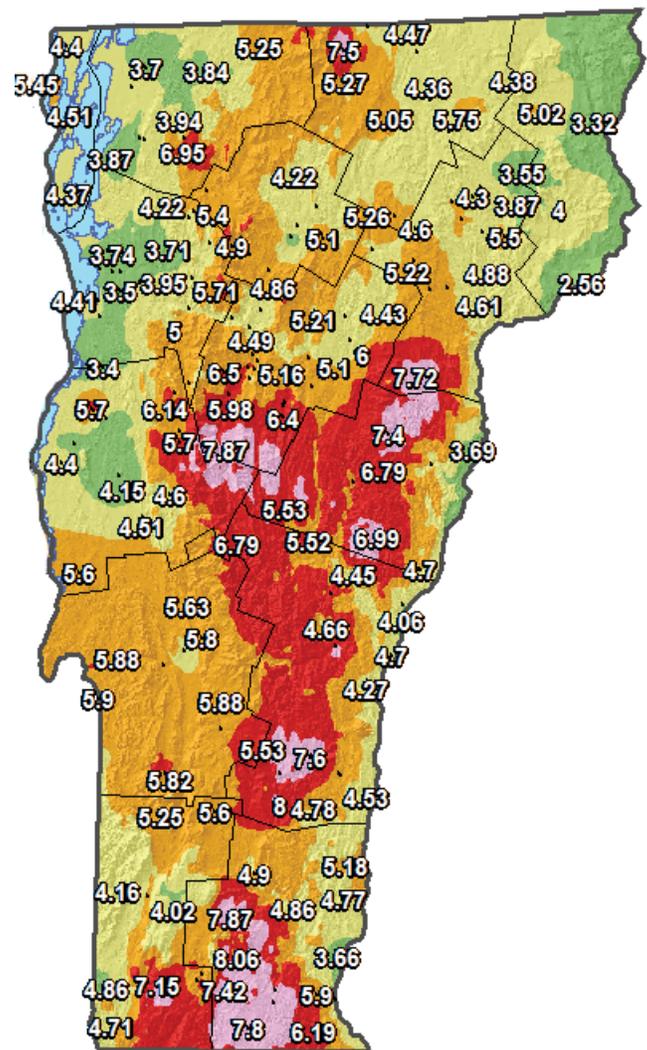


Figure 31: Tropical Storm Irene total rainfall in inches map (August 27-28, 2011)
 Source: National Weather Service

Transportation:

- Roads: >2500 miles of road, ~480 bridges and 960 culverts damaged. Over \$350 million in estimated repairs.
- Railroad: >200 miles of rail and 6 bridges in the State-owned rail system damaged, costing the State an estimated \$21.5 million.
- Emergency Response:
- Main offices for both VEM and ANR were flooded in Waterbury; disaster response headquarters had to be relocated.
- Extensive road damage meant some areas were initially hard to access; 13 communities were without any passable roads leading in or out of town.

Buildings and Infrastructure:

- Power outages for ~158,800 customers.
- 7,215 individuals and families registered for FEMA assistance (by 11/15/11); >\$45.9 million in grants and low interest loans for Vermont residents, businesses, and nonprofit organizations were approved by FEMA and the U.S. Small Business Administration; also, nearly \$15 million loaned to businesses and farms by Vermont Economic Development Authority.
- FEMA completed nearly 5,000 property inspections to document damage; ~1,500 residences had significant damage (433 of these residences were mobile homes) and at least 1,405 households were temporarily or permanently displaced.
- Municipal infrastructure (including transportation) required an estimated \$140 million in FEMA reimbursements, with \$2 million in PA dollars obligated for Tropical Storm Irene as of 12/6/11.
- Waterbury State Office Complex, R.A LaRosa Agriculture and Environmental Laboratory, and Vermont State Hospital severely damaged in flooding, displacing ~1,500 employees; costs to rebuild and upgrade the complex were nearly \$130 million.

Public Health and Safety:

- American Red Cross set up 13 emergency shelters and distributed ~16,000 meals, plus thousands of water bottles.
- A food safety advisory was released for any food touched by floodwaters.

Water Supply:

- About 30 public water systems issued Boil Water Notices; in many cases, broken pipes lowered a system's water pressure, which increased the likelihood of harmful contaminants mixing with treated drinking water. Drinking water advisory were issued for wells submerged by floodwater.
- An estimated 16,590 people in Vermont were affected by Tropical Storm Irene-related Boil Water Notices

Hazardous Waste and Fuel Spills:

- Potentially hazardous waste mobilized along rivers, contaminating floodwaters and sediment and soil deposits.
- In the first week after Tropical Storm Irene, hazardous spills reported to state officials increased over routine levels by a factor of 14; many spills were related to home fuel tank connections breaking as floodwaters moved tanks.

- Both U.S. Environmental Protection Agency (EPA) and Vermont Department of Environmental Conservation (DEC) investigated and assessed hundreds of Irene-related spills; oil-water separators were used to process roughly 300,000 gallons of contaminated waters near the Waterbury state complex.
- Over \$2 million in total costs have been incurred to the State to clean up aboveground storage tank oil spills.

Wastewater Treatment:

- Seventeen municipal wastewater treatment facilities (WWTFs) reported compromised operations, with issues ranging from pump station overflows to incomplete processing of sewage (no structural damages, but damages relating to mechanical, electrical, and debris accumulation problems). Most problems were resolved within 24 hours and the vast majority within one week; estimated discharge of partially unprocessed or raw sewage is 10 million gallons during this period.
- On-site septic systems around the State were also damaged by high groundwater levels and river or stream erosion. In the two months following Irene, State officials tallied 17 septic system failures.

Solid Waste Disposal:

- Vermont landfills received an estimated 32,000–42,000 tons of storm-related waste during the months that followed Irene.
- Household hazardous waste collections around the State amassed an estimated 4,385 gallons and 8,464 units* of waste, with ~\$82,000 cost incurred (*units refer to disposed items and range from small bottles to five-gallon buckets of material).

Forests:

- High flows and saturated ground conditions undermined tree roots, and floating debris injured tree stems. Brief duration of standing water at most locations prevented further near-term tree damage; however, great amounts of accumulated sediment and debris in some streamside forests or establishment of invasive plants may inhibit tree growth over time.
- Aerial surveys found 9,213 acres with trees exhibiting flood damage symptoms from both spring and Tropical Storm Irene-related flooding.
- Green Mountain National Forest reported multiple trail, recreation site, and road closures.

Agriculture:

- Farm fields and barns were washed out or covered with flood sediments and debris; more than 450 farms filed Farm Loss claims with the U.S. Department of Agriculture (USDA), and roughly 20,000 acres of farmland were affected.
- Food advisories forced farmers to throw away food crops that may have been contaminated by floodwaters. Estimated value of crop losses and damage was >\$10 million dollars statewide.
- Producers reported more than 1,000 acres of sugar bush damaged by winds.

Water Resources:

- Intense flooding occurred in at least 10 of Vermont's 17 major river basins, demonstrating record or near record flood crest levels along rivers.
- Otter Creek gage in Center Rutland showed the highest flood crest since the gage began operating 83

years ago—9.21' above flood stage. Mad River gage in Moretown and White River gage in West Hartford both showed second highest flood crests on record – 12.1' and 10.4' above flood stage, respectively.

- Nine stream gaging stations in Vermont recorded peak flows estimated to have a 1% or less chance of occurring or being exceeded in any given year.
- Some river locations appeared relatively unscathed, while others underwent catastrophic channel enlargement, deposition, and relocation; pre-Irene geomorphic studies of many Vermont rivers probably flagged some of these damaged areas as being susceptible to channel adjustment.
- In-stream channel work and gravel removal occurred in multiple locations during Tropical Storm Irene recovery period (largely in the 2-3 months after the flood); in some cases, work occurred without official authorization.

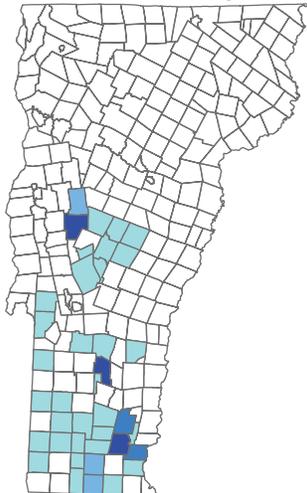
Aquatic Life and Habitat:

- In many locations, daily turbidity of waters (related to in-stream work) and habitat disruption may stress fish and macroinvertebrates (insects, snails, mussels, crayfish, etc.); extreme scour from powerful floodwaters likely reduced total numbers of fish and macroinvertebrates in some rivers, and species composition of fish and macroinvertebrates may shift to species that more readily withstand these stresses. For example, state fish biologists studied wild trout populations in the Mad and Dog River watersheds both before and after major Tropical Storm Irene-related flooding. After the flood, wild trout populations in studied streams were reduced to 33–58 percent of pre-flood levels.
- Fish and macroinvertebrate populations have a long history of surviving floods when quality stream habitat is available, and reduced numbers are usually temporary, but an increase in flood return rate due to changing climate may have long-term impacts. In addition, where habitat is compromised (due to historic channelization practices, encroachment, or post-Irene channel remediation efforts such as streambed excavation and fallen tree removal), fish populations may be affected over a longer term, depending on how quickly natural stream processes can re-establish habitat features.
- Increased algae growth with ongoing influx of river silts (elevating available nutrient levels).
- Mussel populations (including some rare, threatened, or endangered species) were harmed as sand and silt deposition and bank collapse buried and suffocated individuals.
- Japanese knotweed, an invasive plant that spreads by sprouting from broken plant rhizomes, has been spread with flood debris, threatening riparian forests, future bank stability, and agricultural fields.

Mobile Home Parks:

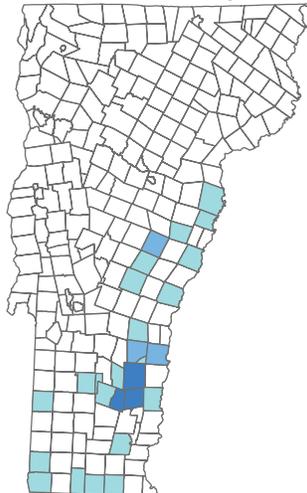
- Mobile homes suffered disproportionately in Irene; mobile homes comprise 15% of the total residences damaged while only accounting for 7% of Vermont's total housing stock.
- 17 mobile home park communities experienced some level of flooding during Irene, with 14 of those parks having at least 1 home destroyed by floodwaters.
- More than 130 mobile homes were completely destroyed.

DR-1336: July 2001



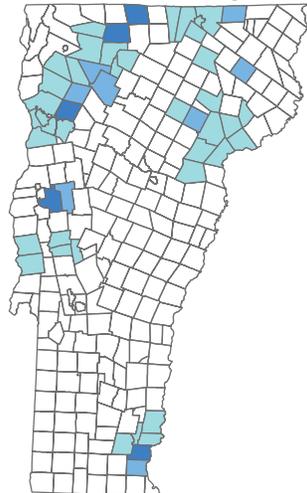
Total: \$2,363,000

DR-1488: July 2003



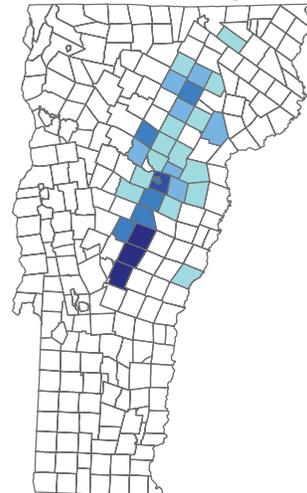
Total: \$916,000

DR-1559: August 2004



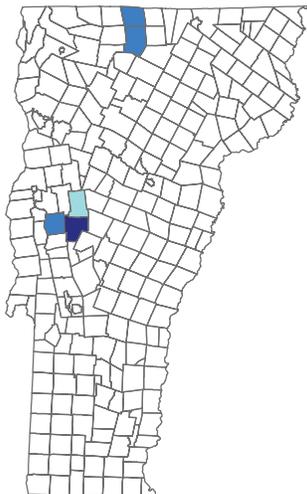
Total: \$2,240,000

DR-1715: July 2007



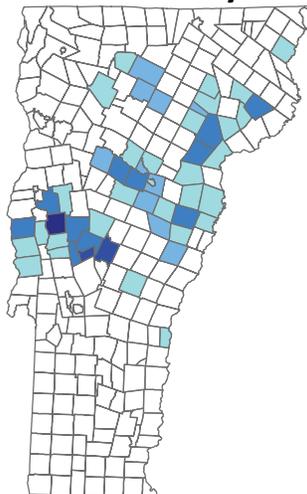
Total: \$4,703,000

DR-1778: June 2008



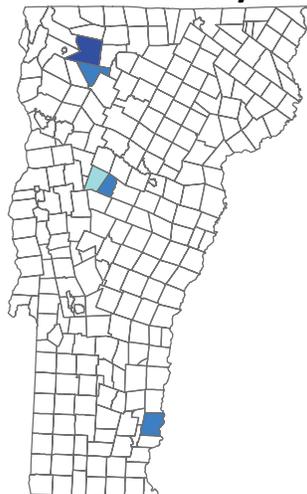
Total: \$1,087,000

DR-1790: July 2008



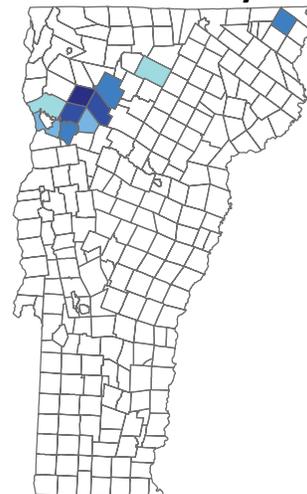
Total: \$4,571,000

DR-4043: May 2011



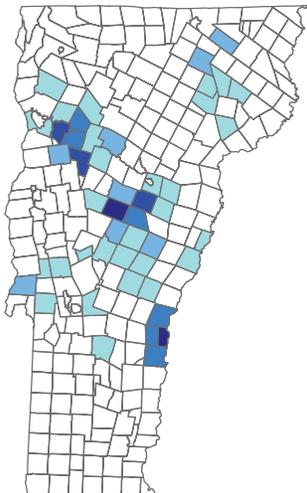
Total: \$946,000

DR-4120: May 2013



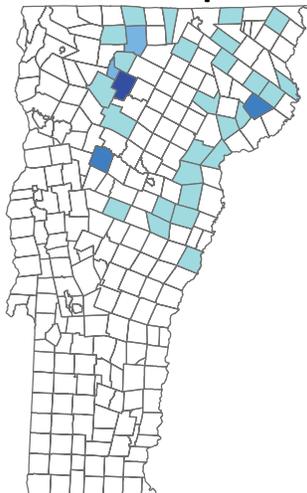
Total: \$1,915,000

DR-4140: June 2013



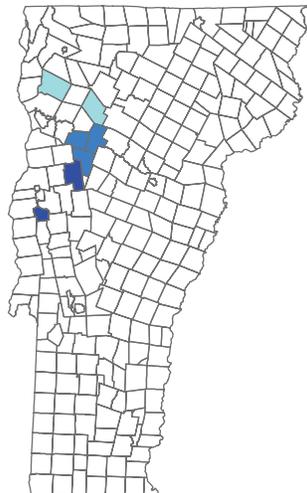
Total: \$5,619,000

DR-4178: April 2014



Total: \$1,824,000

DR-4232: June 2015



Total: \$1,227,000

≤ \$50,000

\$50,001 - \$100,000

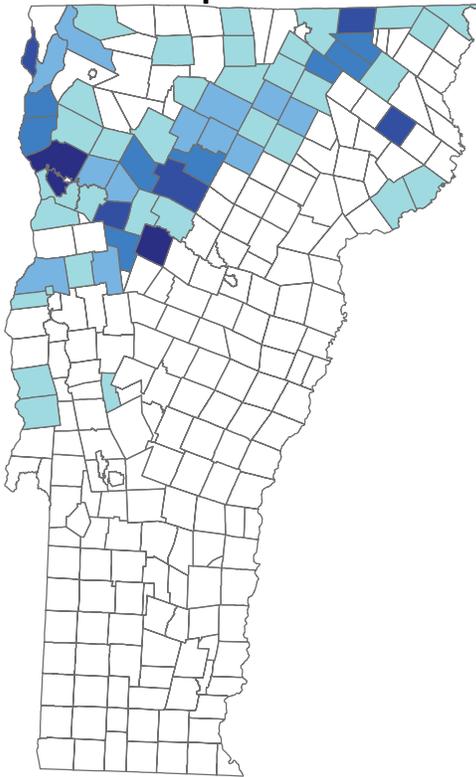
\$100,001 - \$250,000

\$250,001 - \$500,000

\$500,001 - \$1,000,000

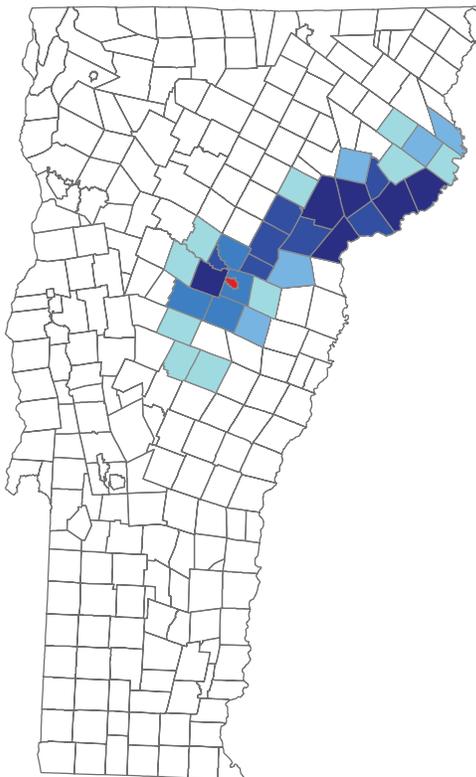


DR-1995: April 2011



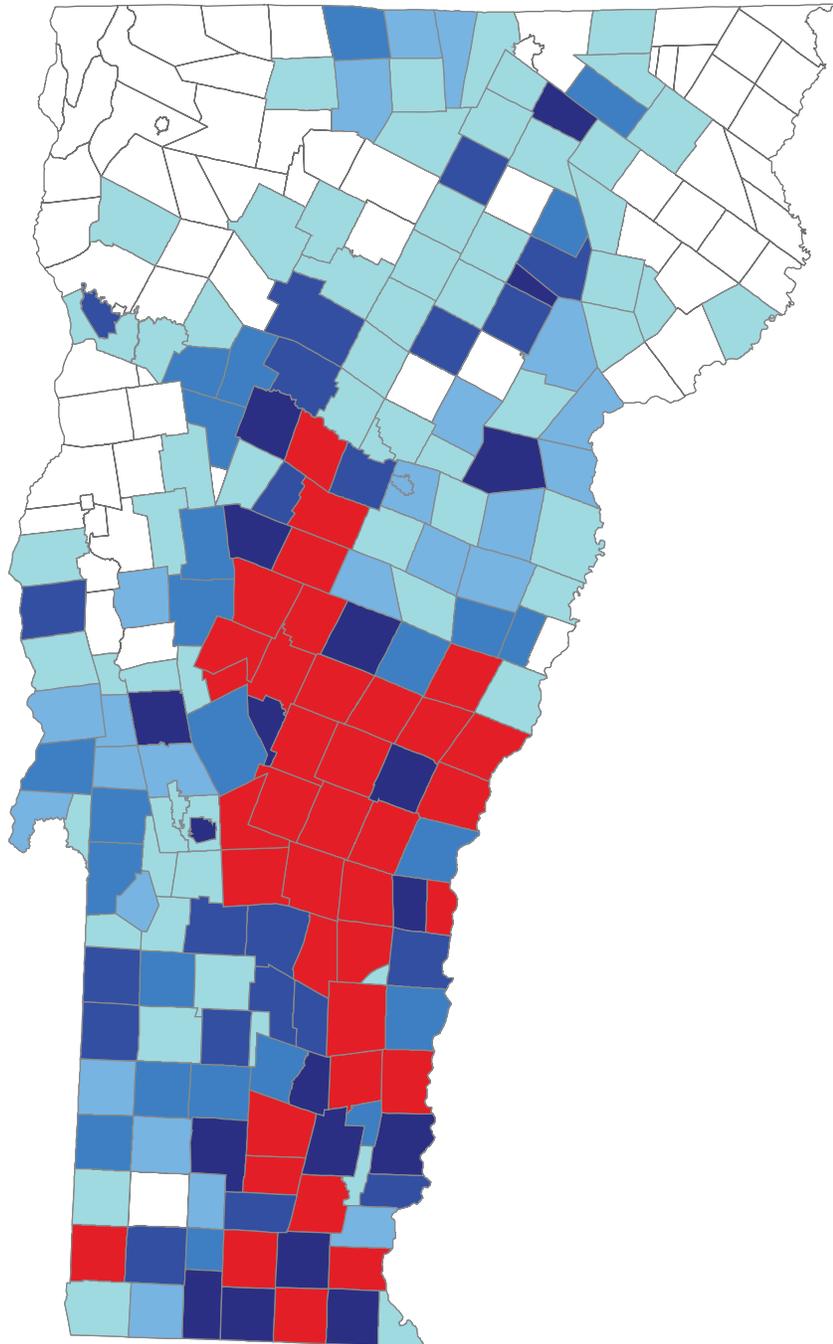
Total: \$10,477,000

DR-4001: July 2011



Total: \$10,674,000

DR-4022: Tropical Storm Irene, September 2011



Total: \$210,461,000

≤ \$50,000
 \$50,001 - \$100,000
 \$100,001 - \$250,000
 \$250,001 - \$500,000
 \$500,001 - \$1,000,000
 ≥ \$1,000,001

Figure 32: Federally declared flooding disaster public assistance expenditure by municipality (2000-2016)

Data Source: www.fema.gov/openfema

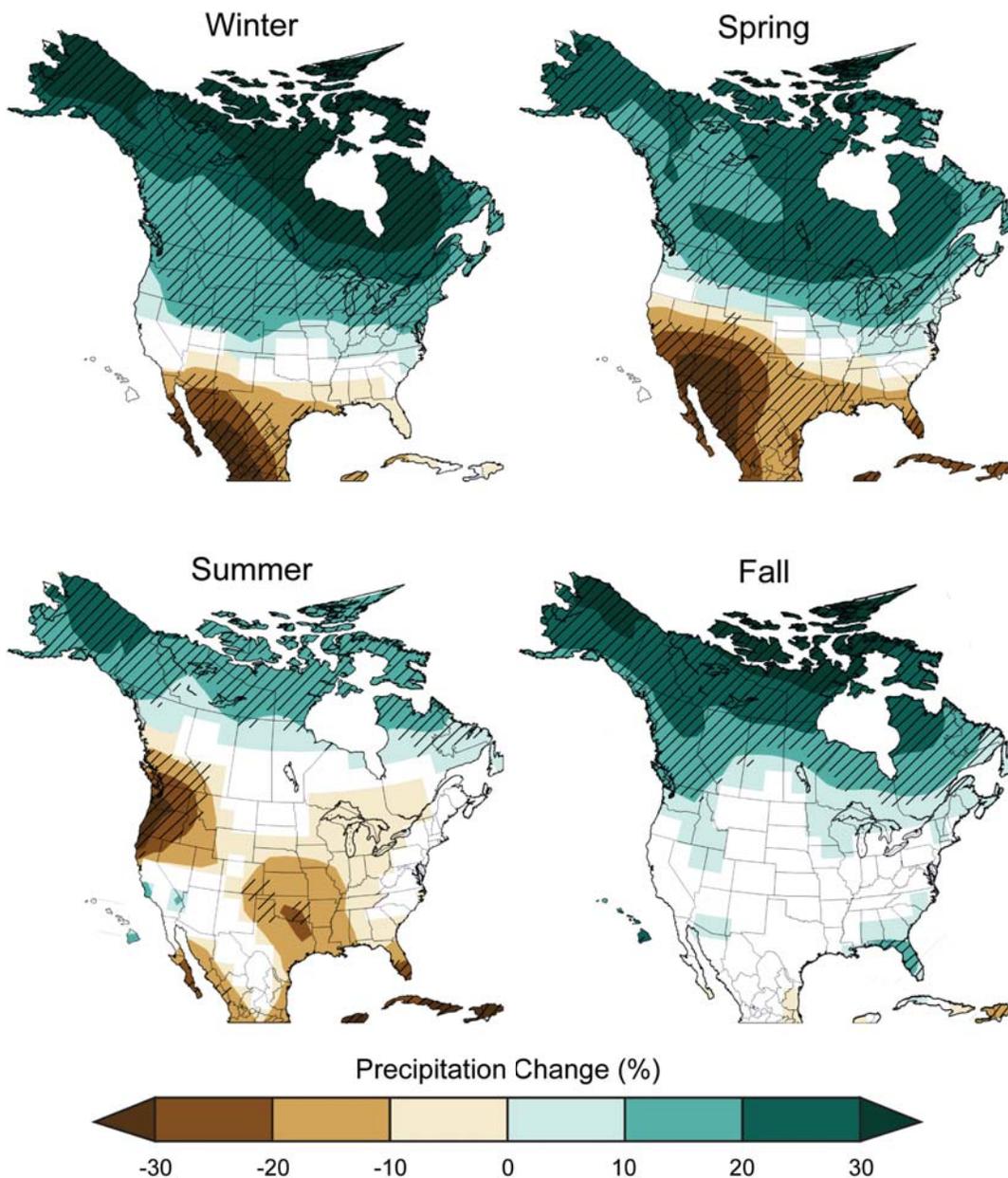


Figure 35: Projected U.S. precipitation change by season, higher emissions scenario (A2)

Source: <https://nca2014.globalchange.gov/report/our-changing-climate/precipitation-change>

In Vermont, average annual precipitation has risen 0.7 inches per decade since 1895 and 1.5 inches per decade since 1960¹¹, suggesting an increasing trend in increased precipitation. Considering observed and projected increases in both the number of high precipitation events and the amount of precipitation, the Steering Committee considered the probability of a plausibly significant event for either inundation flooding or fluvial erosion to be very likely, with significant impacts to infrastructure, the economy, the environment and human life. Because Vermont experiences more damage as pertains to fluvial erosion than inundation flooding, fluvial erosion was ranked the top natural hazard impacting Vermont.

The impacts of both inundation flooding and fluvial erosion are typically far-reaching, disrupting communities by causing damage to the built environment, as well as local and regional economies and ecosystems. Impacts to human life are typically non-fatal, but financial impacts to individuals and families affected by flooding can be significant. Consequently, the State's vulnerabilities to flooding are numerous.

11 <http://climatechange.vermont.gov/our-changing-climate/dashboard/more-annual-precipitation>

Vermont's Annual Precipitation (1960-2015)

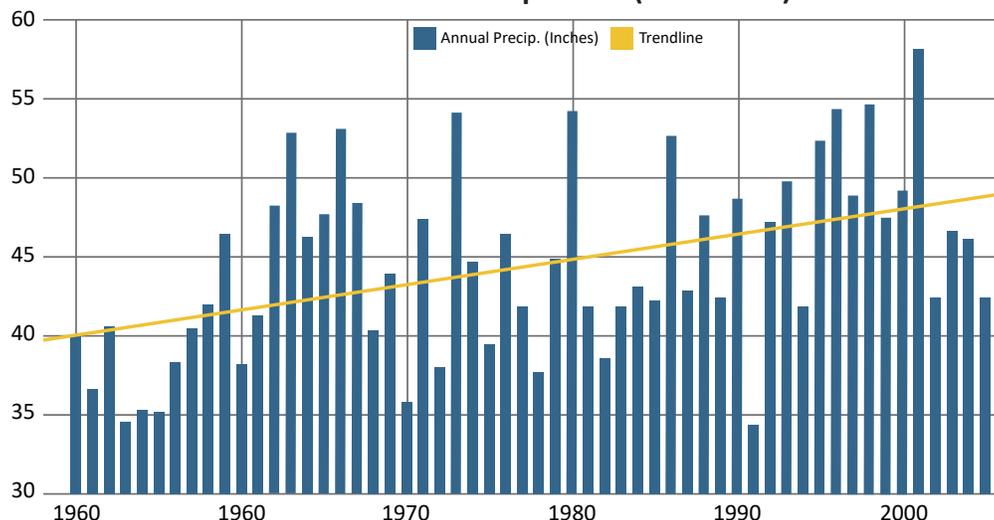


Figure 36: Vermont's annual precipitation (1960-2015)
Source: climatechange.vermont.gov

The anticipated increases in both frequency and magnitude of precipitation in Vermont will lead to alterations to hydrology and water availability. Increased flood inundation, fluvial erosion, and subsequent landslide hazards will result in impacts to ecological and geomorphic integrity of the State's river/floodplain systems, and to the built environment. Vermont's historic settlement pattern, in association with the widespread channelization of rivers and loss of functioning floodplains due to encroachments and fill, make Vermont particularly vulnerable to climate change-related increases in flood frequency and magnitude. Moreover, increases in frequency of periodic drought (see: [Drought](#)) will not only lead to greater demand for new and more reliable water supplies, but will also reduce the ability of soils to quickly absorb floodwaters, thereby exacerbating flood-related impacts.

Fluvial Erosion Vulnerability:

Though all areas of Vermont have the potential to suffer equally from fluvial erosion impacts, some have suffered more than others simply because of the location of storm tracks and significant rainfall. Many storm events impact Vermont from southwest to the Northeast.

Transportation infrastructure and agricultural property are the most vulnerable types of human investment affected by fluvial erosion hazards. Residential, commercial, utility infrastructure and municipal properties are also often vulnerable. Because many of Vermont's historic towns and villages were built along the river for trade and energy purposes, these locations are also at-risk of fluvial erosion within the river corridor.

Worse off are those locations that have historically channelized streams in an attempt to keep the water away from valued lands and



Extensive erosion damaging a home along Route 11 outside of Chester, VT.
Photo Credit: www.mansfieldheliflight.com/flood/

the built environment. These changes in watershed hydrology significantly influence fluvial stability, preventing streams from meandering, thereby increasing stream flow velocities and worsening erosion. Watershed-scale hydrologic changes have been observed in Vermont as a localized phenomenon, most notably in the Moon Brook in Rutland, Stevens Brook in St. Albans City, Morehouse Brook in Winooski, and Centennial Brook and Bartlett Brook in South Burlington. This channelization trend is also observed in small, rural subwatersheds where clear-cutting of a large percentage of the watershed land area has occurred. More extensive, regional channelization with which extensive flood damages have been associated include the White River, West Branch of the Little River, Mad River, Huntington River, Great Brook, Williams River, and North Branch of the Deerfield River. When human investments and land use expectations include all the land in the valley up to the river banks, there results extreme public interest in maintaining this unsustainable morphological condition despite its great cost and consequential hazard to public safety.

Stream geomorphic assessments and a fluvial geomorphic database maintained by the Agency of Natural Resources (ANR) have identified main stem rivers often channelized from 60-95 percent of their lengths. This database is mapped on the ANR website for use by the public for planning and project development¹².

The Vermont Agency of Transportation (VTrans) maintains a list of “scour-critical” stream crossing structures endangered by streambed scour. The 2015 VTrans Hydraulics Manual¹³ addresses channel stability and scouring at bridges as a primary consideration given the consequences of bridge failure, and a 2017 paper detailing a VTrans scour project notes that scour is the leading cause of bridge failure in the United States, with hydraulic/scour-caused damages accounting for 52% of bridge failures¹⁴. The paper identifies only 815 of the over 4,000 hydraulic bridges have a hydraulic and scour report on file, with approximately 25% of the 2,249 inspected bridges receiving a scour critical rating, using the Federal Highway Administration’s (FHWA) National Bridge Inventory coding guide. Should the remaining 1,750+ bridges that have yet to receive an inspected be included in this inventory, it is the assumption of VTrans hydraulic staff that the number of scour critical bridges would increase. As VTrans continues to inspect bridges and identify those that are scour critical, the State will have a better understanding of where its infrastructural vulnerabilities to fluvial erosion are located.

Many other bridges and culverts are endangered by outflanking or debris jams or channel adjustment processes not associated with the structures themselves. Again, there is no specific geographic pattern of distribution; these problems exist uniformly throughout Vermont.

Often, fluvial erosion can lead to more significant slope failures, resulting in costly repairs and mitigation measures for the built environment. In addition to the acquisition and demolition of several properties across the State following Irene-related erosion, VTrans estimates spending approximately \$5.4 million annually on erosion and slope failure projects (see: [Landslides](#)).



Significant scour along the Riford Brook in Braintree caused severe damage to Riford Brook Road during Tropical Storm Irene.

12 <http://anrmaps.vermont.gov/websites/anra5/?LayerTheme=1>

13 <http://vtrans.vermont.gov/sites/aot/files/highway/documents/structures/VTrans%20Hydraulics%20Manual.pdf>

14 <http://vtrans.vermont.gov/sites/aot/files/highway/documents/materialsandresearch/completedprojects/VTrans%20Scour%20Project%20731%20Anderson%20Et%20al%20%28FinalReport%2003-10-17%29.pdf>

Ice Jam Vulnerability:

Incidence of ice jams in the State are also on the rise, with more significant fluctuations in temperature and decreased snow pack creating an environment prone to greater ice accumulation. As precipitation trends in the northeast indicate that the most significant increases are occurring during winter months, rain events could lead to more frequent ice jam events.

The Winooski River and Dog River in Montpelier have been identified as particular areas of interest for ice jams, given the history of ice jams and flooding in these locations. More than a dozen serious ice jams events have occurred in Montpelier since 1900. In 1992, an ice jam in Montpelier led to flood inundation in the downtown area, causing more than \$5 million in damage to buildings, homes, roads, culverts, and other infrastructure facilities. Ice jams in this location have been identified as far back as the 1700s. It is likely that ice jams will continue to pose a threat to Vermont for the foreseeable future, particularly in the months of January and February.

While other jurisdictions have a history of more frequent ice jam flooding, such as Hardwick, Richford, and Richmond, Montpelier's vulnerability to ice jams may represent the most extreme in the State based on the magnitude of the historic and potential economic loss.

From February through March 2007, December 2008, January 2010, and again in January through February 2018, the City of Montpelier and state agencies carefully monitored a large frazil ice jam on the Winooski River at Cemetery Bend, which threatened to flood downtown Montpelier. Strategically placed gages along the river allowed authorities to monitor the height of the river and rate of rise, alarm systems are in place to warn citizens of impending flooding, and an ice jam breaker is parked permanently over the winter along this vulnerable bend in Montpelier should the need arise to break up thick ice in anticipation of potential jamming. In addition, the U.S. Army Corps of Engineers (USACE) Cold Region Research and Engineering Laboratory (CRREL) have established a website with monitoring equipment and gages indicating level of rise, depth of water, and river temperature. This can be accessed by emergency management officials so that sufficient warning can be given if flooding appears to be imminent¹⁵.

15 <http://icejams.crrel.usace.army.mil/apex/f?p=524:1:>



Significant ice jamming along the Lamoille River in Johnson in early 2018 led to concerns of inundation flooding in the town, including for the mobile home park in the background.

There are no known State buildings or facilities (other than roadway infrastructure) immediately endangered by ice jams outside the Berlin, Montpelier, and Waterbury State Office Complexes, although no specific inventory or assessment has been performed.

Significant ice jams have occurred on the Winooski River in Montpelier, the Deerfield river north branch in Wilmington and most recently along the Lamoille River in Johnson and the Missisquoi River in Swanton and Highgate.

Water Quality Implications:

In addition to an increase in the frequency and severity of flooding and fluvial erosion, the greater amount of precipitation that climate change is projected to bring to the Northeast may also detrimentally affect water quality. Higher water inflows into lakes and streams increase phosphorus levels, leading to eutrophication, which is the cause of toxic Cyanobacterial blooms (blue-green algae). Cyanobacterial blooms are harmful to the environment, and toxic to animals and people. When considered together, increases in precipitation and temperature exacerbate both the frequency and magnitude of these harmful algal blooms (see: Extreme Heat). Recreationalists accessing Vermont's many lakes need to consider current water quality, and are encouraged to monitor the Vermont Department of Health's Cyanobacteria Tracker Map to check recent lake reports prior to water-based activity¹⁶.

Mobile Home Park Vulnerability:

Mobile home parks are uniquely vulnerable to flooding. This increased risk is related to siting of park communities in flood hazard areas, socioeconomic characteristics of park residents, and limitations of the structures themselves. An assessment completed in 2012 by researchers at the University of Vermont found that one-fifth of Vermont's 247 mobile home parks have at least one lot that is located within a flood hazard area and nearly 12 percent of all mobile home park lots are located in flood hazards areas.

Two of the major flooding events in 2011 affected 19 mobile home parks across central and southern regions of the State, destroying over 150 mobile homes. Tropical Storm Irene also flooded two parks that are not in mapped flood hazard areas: Barber's Pond Mobile Home Park in Pownal and Tenney's Mobile Home Park in Athens. Both of these parks were located just outside the limit of the mapped flood hazard area.

Lake Flooding Vulnerability:

Because Vermont has no coastal or ocean front areas, coastal flooding is not an issue; however, increasing development pressures on the lake front in Shelburne, Charlotte and Ferrisburgh may be impacted from erosion and storm water runoff and related pollution. The Lake flooding in spring 2011 impacted a large number of communities, as water levels topped well over the 500-year floodplain and remained above the base flood elevation for over a month.

As the trends outlined above indicate greater precipitation and more frequent severe rainfall events, swollen rivers in the Lake Champlain basin will continue to cause lake levels to rise, further impacting the nearby built environment vulnerable to inundation, erosion and water quality challenges.

16 <http://www.healthvermont.gov/tracking/cyanobacteria-tracker>

Invasive Species as an Accelerant to Fluvial Erosion:

Fluvial Erosion can be exacerbated by invasive species. Invasive plants are prevalent along our rivers, outcompete our native species and increase erosion along stream banks.

While the roots of varied native vegetation help to stabilize river banks, Japanese Knotweed can contribute to erosion. Japanese Knotweed spreads quickly once established to crowd out and shade other native species and create a monoculture, with very little other growth below the plant. This leaves bare soil and a shallow root system, which do not support the stability of river banks¹⁷ (see: [Invasive Species](#)).

Potential Flood Losses to State Facilities:

Update with BGS project info when completed.

17 http://www.uvm.edu/~epscor/ds/secure_dir_007.php?file=.staff/open/cwdd/2014%20Symposium/presentations/2_Emily%20Secor_2014.pdf

Repetitive Loss:

FEMA, through the National Flood Insurance Program (NFIP), considers any insurable building for which two or more claims of more than \$1,000 were paid by NFIP within any rolling ten-year period since 1978 to be a Repetitive Loss (RL) property. With over 122,000 RL properties nationwide, FEMA estimates that these flood vulnerable structures have resulted in \$3.5 billion in claims. In 2004, the National Flood Insurance Reform Act went further to define Severe Repetitive Loss (SRL) properties as those single family properties covered under NFIP that have incurred flood-related damage for which four or more separate claims totaling at least \$5,000 each have been paid out, or when there are two or more losses where claim payments exceed the property's value. FEMA estimates that over 6,000 properties in the nation fall under SRL designation¹⁸.

In Vermont, the following communities have the highest number of Repetitive Loss properties, according to FEMA's NFIP listing: Barre, Lyndon/Lyndonville, Montpelier, and Rutland.

Tropical Storm Irene greatly increased the number of repetitive loss properties in Vermont. According to the 2010 Vermont State Hazard Mitigation Plan (SHMP), there were 65 non-mitigated multiple loss properties in the State of Vermont in 33 towns. In the 2013 Vermont SHMP, there were 139 non-mitigated multiple loss properties in 45 communities. As of early March 2018, of the 176 RL properties in Vermont, 163 non-mitigated multiple loss properties are located within 51 communities.

There are also areas within Vermont that present significant losses but do not fall under the FEMA definition of a repetitive loss property. For example, Clover Street in Rutland City is repeatedly flooded by Moon Brook after major rainstorms. It is speculated that the major cause of this flooding is an insufficiently sized culvert under the adjacent railroad bed to the west. The culvert does not meet the cost-benefit ratio to qualify for FEMA Hazard Mitigation Assistance funding, but is a significant threat to the community.

The State of Vermont is committed to ensuring that all repetitive loss properties, whether they meet the FEMA definition or not, are monitored and mitigated to prevent future financial loss and loss of life.

A barrier to potential mitigation of these repetitive loss properties is a discrepancy that exists between the NFIP and HMA branches of FEMA, both of whom keep their own, distinct lists of repetitive loss properties. These lists are not aligned with one another, and the HMA-eligible RL property list is significantly smaller than the NFIP repetitive loss database. For example, as of late 2017, the HMA-eligible RL list was comprised of eight properties, whereas the NFIP list from the same time period listed 176 RL properties, which are considered to be equally vulnerable to flooding.

For a complete list of all communities participating in the NFIP, FEMA keeps an up-to-date Community Status Book Report detailing community information, map effective dates and more¹⁹. Property owners whose communities do not participate in the NFIP do not have access to flood insurance, making them more vulnerable to the financial difficulties following a flood event that damages their property. Additionally, mitigation projects that take place within the FEMA-mapped Special Flood Hazard Area are not eligible for HMA funding if the community applying for funds is not a participating member of the NFIP, which leaves much of the built environment within that community vulnerable to flood damage.

18 https://www.fema.gov/txt/rebuild/repetitive_loss_faqs.txt

19 <https://www.fema.gov/cis/VT.html>

Flood Hazard Area Mapping Deficiencies:

An analysis of digital FIRM data in six counties indicates that 82 percent of stream miles do not have mapped Special Flood Hazard Areas. There is no mandatory flood insurance requirement as a result, yet flood losses are experienced along these flooding sources. Unfortunately, these losses are not documented by way of a flood insurance claim due to lack of coverage.

Additionally, many towns have antiquated data supporting their mapped flood hazard areas, which do not take into account changes in geomorphology, hydraulics or hydrology, leaving many structures mapped incorrectly or not mapped at all. These mapping deficiencies create additional vulnerabilities to Vermont's built environment, as accurate identification of structures relative to flood hazard areas is difficult to ascertain.

Inundation & Fluvial Erosion Mitigation

As a State with a long history of disasters involving inundation flooding and fluvial erosion, taken together with the increasing trends in both annual precipitation and frequency of significant rainfall events, the Steering Committee considers the probability of a plausibly significant flood inundation or fluvial erosion event to be Highly Likely, with the most significant impacts to the built environment and the economy. Both inundation flooding and fluvial erosion events have a similar, moderate impact to human life. With respect to the natural environment, a significant fluvial erosion event will have major impacts, while inundation flooding will only cause minor damage to the environment. Accordingly, the Steering Committee has ranked fluvial erosion as Vermont's top natural hazard, with inundation flooding ranked second.

Given these rankings, as well as the history of flood-related vulnerabilities in Vermont, the majority of the State's mitigation efforts are focused around inundation flooding and fluvial erosion. Some of the high priority themes and strategies are discussed in detail below; for a complete list of the State's efforts regarding flood mitigation, please visit the [Mitigation Strategy](#) and [Capabilities](#) sections.

Buyouts:

Following Tropical Storm Irene, Vermont has been very successful in acquiring and demolishing flood-damaged or flood-vulnerable structures through several funding sources, to include the Hazard Mitigation Grant Program (HMGP), Community Development Block Grant – Disaster Recovery (CDBG-DR), the Vermont Housing & Conservation Board and the Vermont River Conservancy. Nearly 150 properties have been successfully mitigated in what are colloquially referred to across the State as “buyouts”. In recognition of this success, and as the State continues to better understand its structural vulnerability to inundation flooding and fluvial erosion, the Steering and Planning & Policy Committees have identified the establishment of a Statewide conservation and buyout program as a top priority of this plan. A similar action was developed and prioritized in the 2013 Vermont SHMP, for which this more detailed strategy is based.

This strategy aims to not only identify structures vulnerable to flooding and fluvial erosion, but to also take a more proactive approach at purchasing and conserving undeveloped land to prevent altogether future structural vulnerability. Also included in this strategy are actions relating to dedicated funding sources and better data acquisition and use to more comprehensively address vulnerability. In order to achieve this top priority strategy, input from the various Committees and subject matter experts has identified the need to establish a dedicated working group tasked with designing a robust cross-sector buyout program. This working group will involve key stakeholders and will be created in late 2018.

Headwater and Floodplain Storage and Water Quality Co-Benefits:

During the planning process, a strong theme regarding a holistic approach to flood- and erosion-related mitigation continued to surface. That is, Vermont should consider the mitigative value of flood storage in both headwater forests and down-valley river corridors and floodplains, as well as water quality and invasive species implications that may also affect inundation flooding and fluvial erosion.

In addition to guiding development outside of floodplains and river corridors, several high priority mitigation actions were developed under the strategy aimed at improving headwater storage. These actions, which include developing an inventory of critical headwater storage areas and completing a pilot project to demonstrate the co-benefits of upland conservation and downstream flooding, try to take into account the storage capacity of Vermont’s hills and forests. If these areas are conserved and managed appropriately, the risk of downstream flooding due to the amount of water and debris from upland can be reduced.

In addition to reducing flood levels due to water and debris runoff from the headwaters and increasing flood storage in valley floodplains, there are water quality co-benefits that can be achieved when river banks become more stable (i.e., due to floodplain connectivity) and less runoff – potentially carrying pollutants and invasive species – makes its way to the rivers. As excess nutrients and chemicals are carried from farms and roads into a river, that river’s ecosystem is negatively impacted. Eventually, the river will make its way to larger bodies of water (e.g. Lake Champlain), where those nutrients can lead to harmful algal blooms (see: [Extreme Heat](#)). Invasive species, like Japanese knotweed, readily form along waterways, from road ditches to rivers to lakes, and spread very easily. Their shallow root systems lead to greater bank instability and can further exacerbate not only fluvial erosion, but also water quality issues (see: [Invasive Species](#)).

Given the above, the Steering Committee and Working and Focus Groups recognized the need for a whole systems approach to flood-related mitigation. The result is a high priority strategy devoted to connecting water quality, flood resilience and native habitat connectivity through recognizing co-benefits of mitigation efforts. There are several grant programs that focus within their own silos, but which could be expanded and leveraged to support these co-benefits. By inventorying the many grant programs and capabilities within the State, new projects supporting both water quality and fluvial erosion mitigation, for example, can be realized.

Education, Outreach & Data:

With all of the initiatives, grant programs, data and mapping supporting flood mitigation, especially post-Irene efforts, the State of Vermont’s Department of Environmental Conservation (DEC) developed the Flood Ready website²⁰ as a resource hub for users to access flood-related information. This website, updated daily by multiple State agencies, has received recognition at national conferences and continues to be a primary platform for disbursing useful information, such as grant opportunities, new legislation and community-based reports as pertains to flooding.

In 2018, DEC, with funding from the Lake Champlain Basin Program, created the Flood Training website²¹ which provides a suite of case studies and tools and education materials geared at helping municipal officials protect river corridors and floodplains in their communities.

Because seven years have passed since Tropical Storm Irene brought devastation to the State, flood mitigation outreach is not as impactful as it was in the immediate aftermath of the storm. Many call this phenomenon resilience fatigue, and using language like “100-year” and “500-year” floodplain has led to a lack of

20 <http://floodready.vermont.gov/>

21 <http://floodtraining.vermont.gov/>

understanding of the State's vulnerability to flooding. In an effort to continue outreach efforts and expand education regarding flood risks and the importance of mitigation, the Steering Committee prioritized several education-based mitigation actions as part of this plan update process.

As a primary tool of education and outreach, accurate data and mapping are critical. Accordingly, the Steering Committee has prioritized several actions that fall under the hazard mitigation mapping, data and research coordination strategy, identifying these actions as critical to expand flood resilience by dovetailing research efforts and sharing hazard data. For example, river corridor mapping is used to identify those areas vulnerable to fluvial erosion, identified above as the top natural hazard impacting Vermont. The data used to develop river corridor maps have been compiled over the years through the tireless efforts of DEC and mapped using funding from a myriad of state and federal sources. Publishing these maps on the Vermont Natural Resources Atlas allows the State, municipalities and individuals to better understand fluvial erosion vulnerability and develop steps to address it. It is important to note, however, that without recognition of this river corridor area by all agencies at the state and federal levels, Vermont remains vulnerable to fluvial erosion. The Academic Resilience Collaborative (ARC), a high priority action of this plan, will be tasked with addressing fluvial erosion data and research needs and potentially creating an algorithm or model for inclusion of fluvial erosion in the FEMA Benefit-Cost Analysis (BCA) software so that Vermont can access mitigation funds for its primary hazard. Vermont has also applied for several FEMA HMGP 5% Initiative applications aimed at accomplishing increased awareness of flood vulnerability and mitigation and will continue to request these funds in the future.

Lake Champlain:

Taking into consideration both the significant lake flooding and erosion along Lake Champlain in 2011 and increased pressures for lake front development, the Vermont Legislature passed into law the Shoreland Protection Act, which regulates activities within 250 feet of the mean water level of lakes greater than 10 acres in size. The intent of this Act is to allow reasonable development along the shorelands of lakes and ponds while protecting aquatic habitat, water quality and reducing erosion hazards by maintaining the natural stability of shorelines²².

Further considerations of inundation and fluvial erosion vulnerabilities along Lake Champlain are being discussed by the International Joint Commission's (IJC) Lake Champlain and Richelieu River Study Board²³.

Though they do not technically meet the definition of coasts, there is currently an effort to analyze and map the shores of the Great Lakes using analyses and procedures standard along the coasts. Performing a coastal analysis of Lake Champlain would add storm surge and wave height considerations to the existing Base Flood Elevation (BFE), which is based strictly on stillwater inundation levels. Though not a current strategy of this plan, future planning and funding efforts should review the results of the Great Lakes study and consider extending the analysis to Lake Champlain²⁴.

Dam Resilience:

With over 800 dams in the State, approximately 70 of which are classified as HIGH hazard, the Steering Committee developed several mitigation actions that fall under the dam resilience improvement strategy. In addition to those actions, there are several other mitigation efforts underway in the State to address vulnerability to dam-related hazards.

The DEC staffs two full-time Dam Safety Engineers who review permit applications for new dams, rehabilitation

22 http://dec.vermont.gov/sites/dec/files/wsm/lakes/docs/Shoreland/lp_ShorelandHandbook.pdf

23 http://www.ijc.org/en_/Lake_Champlain_Basin

24 <http://www.greatlakescoast.org/great-lakes-coastal-analysis-and-mapping/>

of existing dams, and dam removal, conduct dam safety inspections, and work with dam owners to address operation and maintenance issues and larger deficiencies. In addition, the DEC owns and operates the Winooski River Flood Control Dams (Waterbury, Wrightsville, and East Barre), as well as 11 other dams throughout the State. DEC also assists other State Agencies including Fish & Wildlife, Forests Parks and Recreation, and Agency of Transportation, who in total, own approximately 90 dams.

The PUC administers 4.500, Safety of Hydroelectric Dams, rules developed for dams in their jurisdiction. The PUC consists of a team of environmental technicians and lawyers who have the authority to contract with dam safety consultants for assistance on an as-needed basis.

FERC and Federal Agencies that own dams have robust dam safety staff and guidance backed by nationally accepted standards. The New England District of the USACE own and operate large flood control dams in the Connecticut River drainage basin.

The Vermont Dam Task Force, a group of individuals from both the public and private sector, meet quarterly to discuss dam mitigation, with a primary goal of rehabilitating rivers and improving public safety through dam removal. Finally, The Nature Conservancy of Vermont developed a Dam Removal Screening Tool for the Lake Champlain basin, which categorizes dams by their ecological impact. Recognizing the value of this tool, the Steering Committee prioritized expansion of the tool to other watersheds across the State.

Other Initiatives:

In 2015, the Agency of Commerce and Community Development (ACCD), together with VTrans, the Department of Environmental Conservation (DEC), five Regional Planning Commissions (RPCs) and the US Economic Development Administration (US EDA) developed a robust mitigation project identification report for five pilot towns²⁵. This report, titled Vermont Economic Resilience Initiative (VERI), is being used by various agencies to plan for and implement community-identified high priority actions to promote their resilience. Of the five pilot towns, four identified mobile home park vulnerability to flood-related hazards as a priority for project and funding consideration. Since the release of the VERI report, the pilot towns have been working with various State agencies to achieve some of these projects, to include structural elevations and acquisition/demolition of the flood-vulnerable mobile home parks.

The Vermont chapter of the United States Army Corps of Engineers (USACE) Silver Jackets was chartered in August 2016, with representation from various federal (FEMA, USGS, USACE, and NOAA) and state (DEC, VEM, VTrans and ACCD) agencies. The mission of the Vermont Silver Jackets team is to foster innovative and collaborate partnerships that facilitate and contribute to comprehensive and sustainable management of flood risk throughout the State. Following execution of the charter, the Team began working on its first pilot application for improved flood inundation mapping for the City of Montpelier. This application was approved by USACE and work is currently underway. Other projects that the Team is developing in 2018 include new HEC-RAS modeling for the volatile Whetstone Brook in Brattleboro, a project identified in the Brattleboro chapter of the VERI report, and ice jam modeling along the Lamoille River in Johnson and the Missisquoi in Swanton following the significant ice jam events along those two stretches in early 2018. Together with VEM and ANR, the Vermont Silver Jackets Team is identified as a lead entity for the development of a Benefit/Cost Analysis methodology to facilitate buyouts in areas at risk from flood-related erosion and outside of FEMA-mapped Special Flood Hazard Areas.

A plethora of other mitigation efforts, initiatives and capabilities are underway or being developed in Vermont to address the State's top two natural hazards. For more information on these efforts, please see the [Mitigation Strategy](#) and [Capabilities](#) sections.