6. Climate and Climate Change in Vermont

Citation: Dupigny-Giroux, L.A., Shafer, J., Kulkani, T., Bowden, B., Dow, J., Paske, C., Dejong, B., Kim, J., Myrick, E. “Climate and Climate Change in Vermont,” *Vermont Climate Action Plan 2025*. Montpelier, VT, 2025.

Preface

This section of the *Vermont Climate Action Plan 2025* presents the land, air, water and plant dimensions of climate change in Vermont and the interconnected ways that we as peoples both affect and are impacted by such changes. From the homelands of the Abenaki and the Mohican, we honor all ways of knowing[3] and present mitigation, adaptation and resilience through the overlapping lenses of natural hazards, inclusion and vulnerability of peoples, the natural environment, and human infrastructure, as we seek to do no harm. For consistency with other state-level Climate Action Plans, this section uses data, methodologies and results developed in support of the 2023 Fifth National Climate Assessment (NCA5)[4] as well as those from multiple federal and State of Vermont agencies. Following the presentation style used in NCA documents, information here will be organized into Key Messages that highlight updates and developments made since the Initial Vermont Climate Action Plan of 2021.

3 Betts, A.K,. Climate change and society[J]. AIMS Geosciences, 2021, 7(2): 194-218. DOI: 10.3934/geosci.2021012

4 USGCRP, 2023: Fifth National Climate Assessment. Crimmins, A.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA.

Setting the Stage for the Ongoing Impacts of Our Changing Climate

There are three main factors that influence our past, present and future susceptibility to weather and climate events and their changes. These include Vermont's geology, topography or physical geography, its culture and history that predate us, and which in turn have influenced the social and economic decisions and choices that have been made. The geology and physical geography of Vermont influence where natural hazards occur, their impacts on human settlements, the location of major roadways in steep V-shaped valleys, and our ability to increase resilience as a state. From a geologic perspective, large swaths of the state are inherently susceptible to failure due to the glacial stratigraphy (Figure 6.1a). For example, loose sand often directly overlies dense glacial till or glacial lake clays and silts, which sets up a significant permeability contrast and leads to saturation of the overlying sands. This saturation reduces soil cohesion, particularly when located along the steep slopes of the Green Mountains. The north-south spine of the Green Mountains along with the complex east-west valleys and the north-south ridges of the Taconic Mountains affect the movement of localized winds and the incidence of freezing rain conditions, produce enhanced orographic precipitation and associated flooding events, and control the incidence of air pollution and stagnation events as well as variations in freeze and frost dates. Figure 6.1a highlights the locations of landslides and mass movements across the state, while the 2023 U.S. Department of Agriculture's (USDA)'s Plant Hardiness Zone map shows the shift in zones as our climate has warmed (Figure 6.1b).

Apart from landslides, various online tools can be used to map Vermont's exposure to multiple weather and climate-related hazards in each of its 184 Census tracts. One such tool is the NOAA National Centers for Environmental Information (NCEI)'s Billion-Dollar Weather and Climate Disasters mapping tool.[5] Figure 6.1c shows the weather and climate risk from seven hazards. Vermont as a whole has a risk score of 7.52 compared to the national average of 13.30. However, it is important to note that some counties have higher risk scores, such as Windsor County (12.15), Rutland County (10.97) and Washington County (10.36). Also of note is that risk scores vary by hazard. For example, in the case of flooding, Vermont's risk score of 9.13 is the same as the national average, with Windsor County (16.07), Rutland County (14.16) and Washington County (13.77) again exceeding the statewide and national levels. Of particular note is Census tract 9660 (Town of Windsor) in Windsor County, which has the highest hazard risk both overall (23.95) and in terms of flooding (37.07).

5 After 2024, new data will not be added to this tool.

FIGURE 6.1a: Documented Landslides, Vermont Geological Survey.

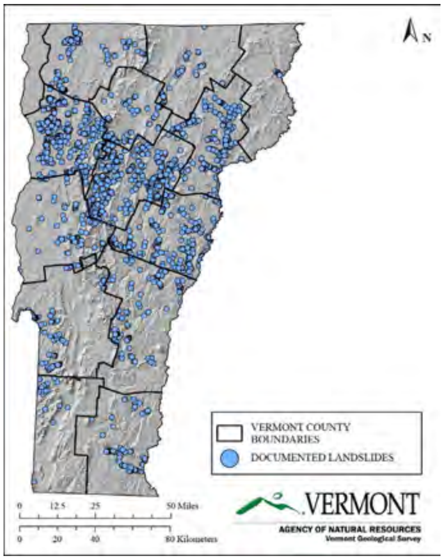

FIGURE 6.1b: 2023 USDA Plant Hardiness Zone Map.

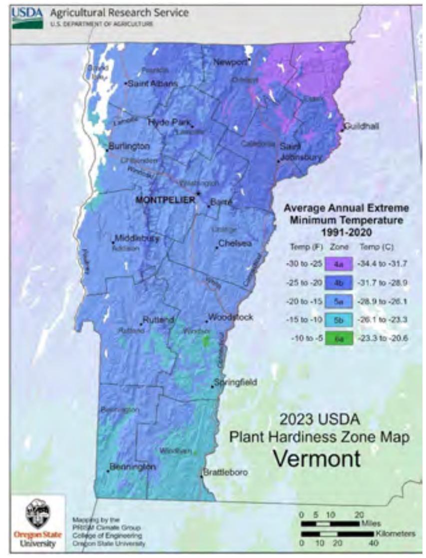

FIGURE 6.1c: Weather and Climate Hazard Risk.

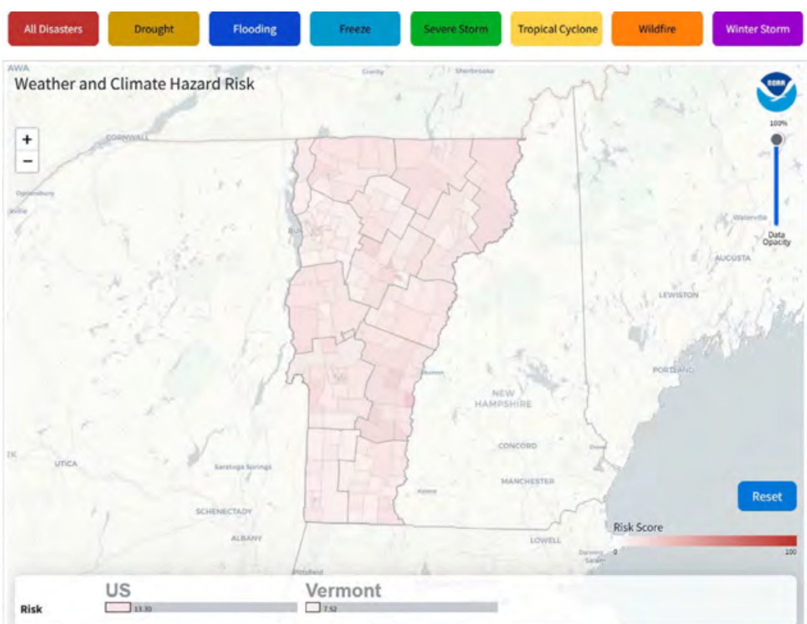

Figure 6.1: Maps of Vermont's counties and census tracts showing (6.1a) the locations where landslides have been documented (Vermont Geological Survey); (6.1b) showing the 2023 USDA Plant Hardiness Zone (Map by PRISM Climate Group, College of Engineering, Oregon State University)[6]; (6.1c) showing the degree of risk (0- 100) from seven weather and climate hazards (drought, flooding, freeze, severe storm, tropical cyclone, wildfire, winter storm, all) (NOAA National Centers for Environmental Information).[7]

6 USDA Plant Hardiness Zone Map, 2023. Agricultural Research Service, U.S. Department of Agriculture.

7 NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2025). DOI: 10.25921

Key Message 1: Our seasons are changing, with the largest changes being observed during the winter

Vermont is characterized by a great deal of climate variability, particularly with regard to precipitation. Climate variability includes the variations that occur from one year to the next and can include changes in the storm tracks observed. Recent examples of the year-to-year differences in storm tracks (and resulting slope failures) were observed during the north-south flooding rains of July 2023 versus the northeast-southwest track of July 2024 (Figure 6.2d). While long-term trends show an increase in total precipitation across Vermont, this does not mean each individual storm is wetter than the last. In fact, as Figure 6.3b shows, in August 2011 Tropical Storm Irene produced more rainfall over a larger geographic area than the flooding rains of July 2023. Even more importantly, heavy precipitation (both snow and rain) can occur during single-day events as well as multi-day ones, where the latter have been increasing in frequency over time.[8] The National Weather Service also calculated that the number of days on which at least 1" of precipitation fell at the Burlington International Airport has recently increased from about 4 days per year (earlier in the record, which starts at 1940) to 6.5 days.

8 Crossett, C.C., Dupigny-Giroux, L.-A.L., Kunkel, K.E., Betts, A,K. and Bomblies, A., (2023) "Synoptic Typing of Multiduration, Heavy Precipitation Records in the Northeastern United States: 1895-2017, Journal of Applied Meteorology and Climatology"

FIGURE 6.2a: Map of annual exceedance probabilities.

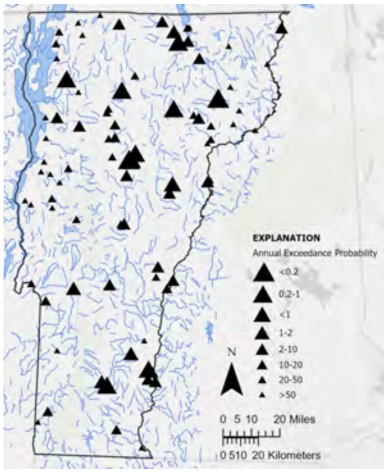

FIGURE 6.2b: Douglas Flood Rock.

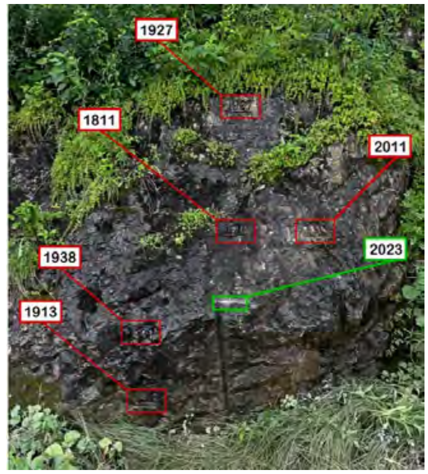

FIGURE 6.2c: Rainfall and roadway impact, July 10–11, 2023.

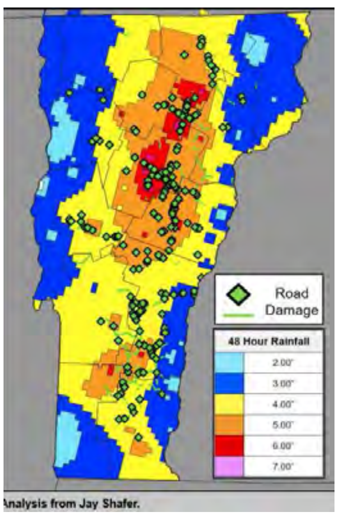

FIGURE 6.2d: Rainfall and landslides, 2023 and 2024.

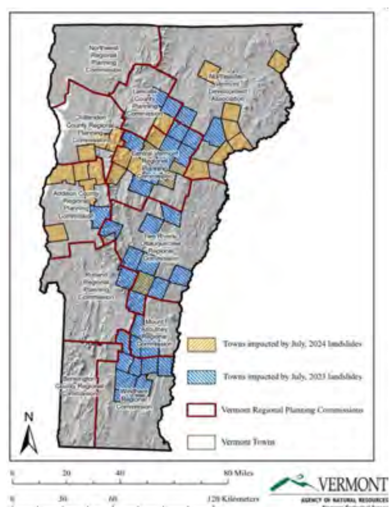

Figure 6.2: Spotlight on the catastrophic flooding of July 9–11, 2023.

(6.2a) “A map of annual exceedance probabilities calculated for the 82 stream gauges in Vermont for a July 2023 flood event. It shows the locations where events of various probabilities occurred, from the at-least-2-year events (smallest black triangles) up to the at-least-500-year events (largest black triangles).” (USGS New England Water Science Center)

(6.2b) “The “Douglas Flood Rock,” has been used to document floods near Otter Creek in Pittsford, Vermont, since 1811. Local engravers mark the highest water level after every big flood event—including July 2023. Locally called “Flood Rock,” this marble ledge is listed in the Pittsford Second Sentry Historical Book.” (USGS New England Water Science Center)

(6.2c) Locations of road damage. (Jason Shafer, formerly of Disaster Tech)

(6.2d) North-south track of the rainfall and subsequent landslides in 2023 compared to the east-west rainfall track and landslides in July 2024. (Vermont Geological Survey, National Weather Service Burlington, Vermont)

FIGURE 6.3a: Top weather events for Vermont.

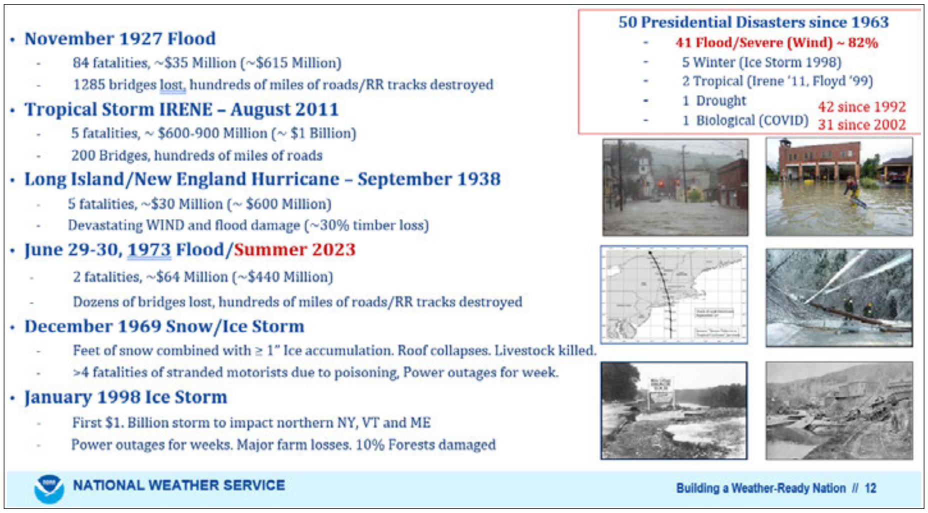

FIGURE 6.3b: Rainfall comparison July 10-11, 2023 and August 27-28, 2011

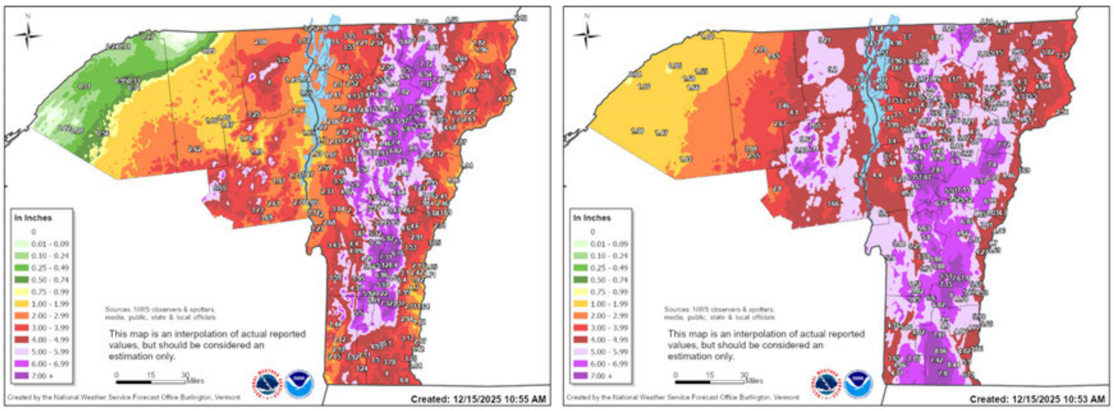

FIGURE 6.3c: North Country and Vermont storm total rainfall ending July 11, 2024.

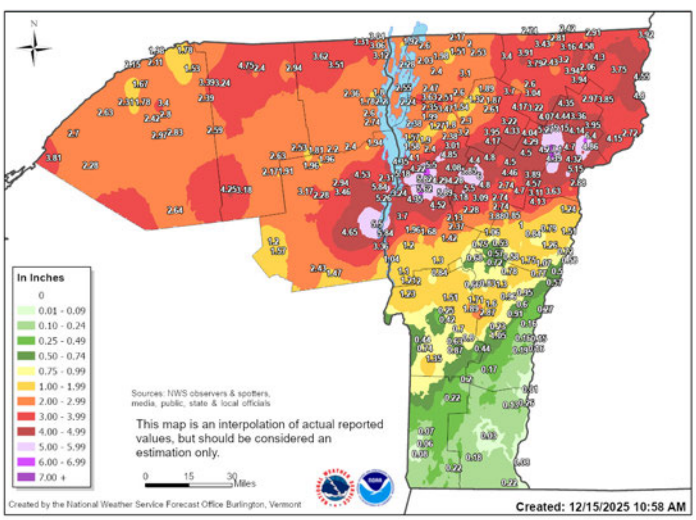

Figure 6.3: (6.3a) The most significant weather events across Vermont in the 1927–2023 period. Rainfall comparison among (6.3b) Tropical Storm Irene (August 27–28, 2011) and the flooding rains of July 10–11, 2023, and (6.3c) July 10–11, 2024. Note the heavier and more widespread totals during Tropical Storm Irene, the north-south track in 2023, and northeast-southwest track in 2024. (Data courtesy the National Weather Service Burlington, Vermont).

Increasingly, Vermont has also experienced what are called “temporally compounding” events where a hazard or event occurs one after the next.[9] Examples of such events include the frosts in the spring of 2023, which were followed by the droughts in June, wildland fire smoke from Canada in June and July, and the flooding rains of July and August of that year. Such back-to-back events have disproportionate impacts on key socioeconomic sectors such as agriculture. It is also very challenging to convey messaging to Vermonters about human and other responses to these complex, overlapping or sequential events.

Vermont’s seasons are changing[10] with backward or false springs[11], [12] during which snow and cold temperatures as late as April and May have been observed. It is important to note that our winters are changing the most rapidly. As Figure 6.4a shows, the 2023–2024 winter was the warmest on record since 1895 across almost all of Vermont, upstate New York and five other High Plains states. The National Weather Service calculates that the winters in the Champlain Valley have warmed by 8.4°F, compared to the annual value of 4.8°F. While seven of the warmest 10 winters in the 1941–2024 period at the Burlington International Airport (Figure 6.4b) were observed since the 2001–2002 winter, it is important to note that bone-chilling cold continues to occur across Vermont (e.g., January 31–February 6, 2021, as shown on Figure 6.4c). Warming winter seasons pose particular challenges for the utilities sector because increases in snowstorms lead to more outages from wet snow falling near the freezing mark. NOAA’s Billion-Dollar Weather and Climate Disasters tool (Figure 6.4d) shows that the greatest number of damaging events occurred in January during the 1980–2024 period. Shorter winters with increased precipitation also affect the timing and thickness of the ice that forms on lakes and ponds, as highlighted in “Conditions on the Ice Are Changing” (p. 32) which spotlights the braiding of Traditional Ecological Knowledge and Western science.

9 Singh, D., A.R. Crimmins, J.M. Pflug, P.L. Barnard, J.F. Helgeson, A. Hoell, F.H. Jacobs, M.G. Jacox, A. Jerolleman, and M.F. Wehner, 2023: Focus on compound events. In: Fifth National Climate Assessment. Crimmins, A.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA.

10 Dupigny-Giroux, L.A., E.L. Mecray, M.D. Lemcke-Stampone, G.A. Hodgkins, E.E. Lentz, K.E. Mills, E.D. Lane, R. Miller, D.Y. Hollinger, W.D. Solecki, G.A. Wellenius, P.E. Sheffield, A.B. MacDonald, and C. Caldwell, 2018: Northeast. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 669–742. DOI: 10.7930/NCA4.2018.CH18

11 Dupigny-Giroux, L.-A.L., 2009: Backward seasons, droughts and other bioclimatic indicators of variability. In: Historical Climate Variability and Impacts in North America. Dupigny-Giroux, L.-A. and C.J. Mock, Eds. Springer Netherlands, Dordrecht, 231–250.

12 Runkle, J., K.E. Kunkel, S.M. Champion, L.-A. Dupigny-Giroux, and J. Spaccio, 2022: Vermont State Climate Summary 2022. NOAA Technical Report NESDIS 150-VT. NOAA/NESDIS, Silver Spring, MD, 4 pp.

FIGURE 6.4a: Temperature ranking, Dec 2023–Feb 2024 (since 1895–1896).

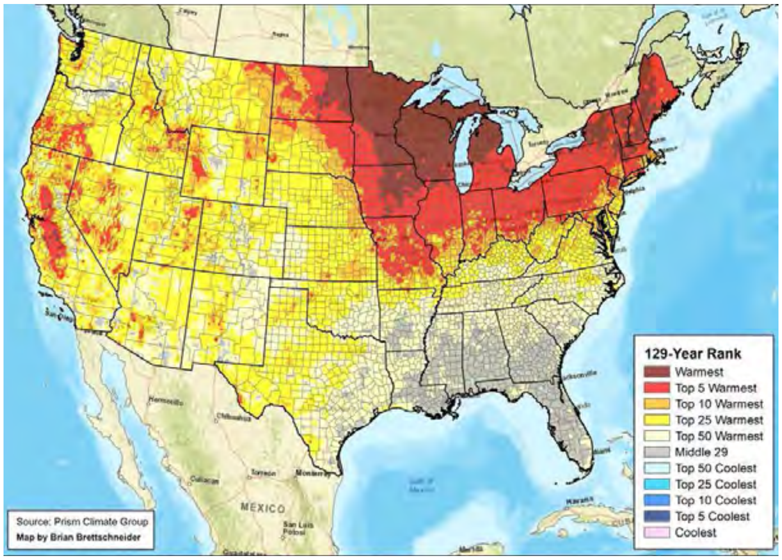

FIGURE 6.4b: Top 10 warmest winters at Burlington (1941–2024).

Rank	Season	Mean Average Temperature
1	2023-2024	30.7˚F
2	2015-2016	30.1˚F
3	2016-2017	29.5˚F
4	2022-2023	29.0˚F
5	2001-2002	28.7˚F
6	2011-2012	27.8˚F
7	2019-2020	26.1˚F
8	1948-1949	25.8˚F
9	1996-1997	25.6˚F
-	1952-1953	25.6˚F

FIGURE 6.4c: Extreme minimum temperature.

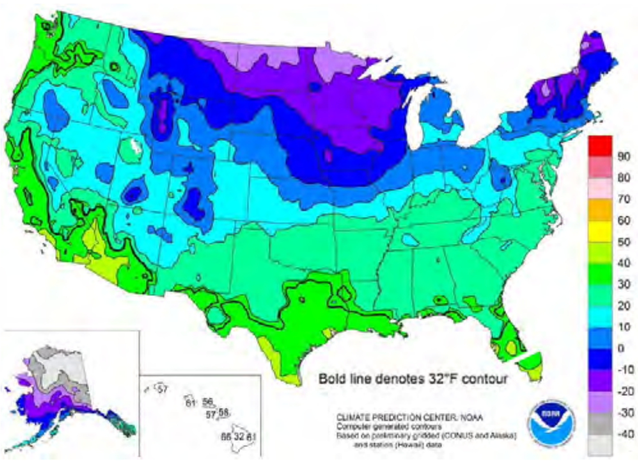

FIGURE 6.4d: Vermont billion-dollar disaster type counts by month, 1980–2024.

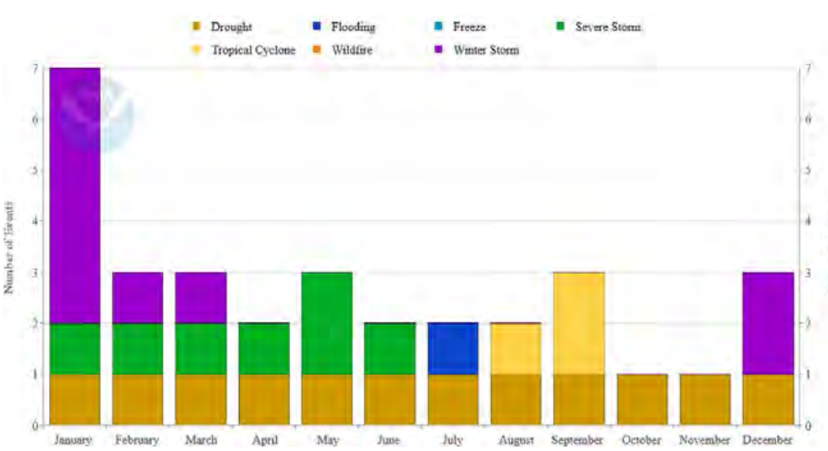

Figure 6.4: (6.4a) A map of the continental U.S. for the winter (December–February) of 2023–2024 showing the rankings by counties since the 1895–1896 winter. Counties with the darkest red experienced the warmest winter since 1985–1896. No counties experienced record cold conditions (NOAA and NOAA National Weather Service). (6.4b) A table of the top 10 warmest winters at the Burlington International Airport since 1941 (NOAA and NOAA National Weather Service). (6.4c) A map of the U.S. for January 31–February 6, 2021, when bone-chilling temperatures as low as -20°F were observed over most of Vermont (NOAA and NOAA National Weather Service). (6.4d) During 1980–2024, the costliest hazards in Vermont were winter storms in the month of January (NOAA NCEI Billion Dollar Disasters Tool).

Conditions on the Ice are Changing

by Judy Dow




Ice out is a special time for Wabanaki people. It is a sign of the arrival of spring, a sign of new beginnings. In the Wabanaki traditions gifts of seeds are placed on the flow to bring new life to places on the shoreline. *Ice out* is honored and respected.

Signs of thinning ice are when the ice pulls away from the shoreline leaving water exposed. Thinning ice is a hazard, yet people try to ignore the dangers to survive on the fish they catch. Traditional knowledges are forgotten and safety goes out the window when you are hungry.

When the ice starts to pull away from the shore and the ice looks black or honeycomb-like you should question going out. Honeycomb-like structures are porous and due to the hexagonal nature of ice crystals, water seeps through the cracks. It's not safe. Things are changing and moving. Show respect for the power of the ice.

Ice fishing on the edge of open water is dangerous especially with a strong south wind. The ice will soon be on the shoreline stacked up like checkers.

A good strong south wind will force the ice to break up and push under the attached ice sometimes reaching 16 inches or more of broken pieces of ice. It gives you a sense of security that is not there. The ice may seem thick but the ice is the deceptive honeycomb and not safe at all. Eventually it piles up on shore.

The National Weather Service (NWS) maintains a record of dates on which Lake Champlain was closed, dating back to 1816. This dataset provides a valuable 200-year proxy for historical winter severity and climate trends. The early part of the record is based on historical climate content analysis from reports and shipping logs, with observations beginning in 1906. In recent times, with the advent of low Earth orbit (LEO) satellites, data from the visible band images on cloud-free days are used to determine whether the lake is completely frozen over (closed). Since 2008, Lake Champlain has rarely closed.

Driven by the observations of drownings that happened when individuals fell through thin ice or capsized in a small boat while air temperatures were warm but water temperatures were cold (50°F or colder), the NWS undertook a study of the cold-water and ice-related injuries in Vermont and upstate New York for the 1990–2023 timeframe. The study highlighted the fact that the climatology of the ice has changed over time and "it's not your grandfather's ice" anymore.[13] Of the 59 incidents investigated, most occurred during ice fishing (45.2%) and driving/riding (29.8%) (Figure 6.5a). Children (aged 12 and younger) and individuals aged 50 and older were more often involved in ice-related incidents, while adults in the 20–29 age range accounted for the majority of cold-water boating accidents (Figure 6.5b).[14]

FIGURE 6.5a: What were people doing on the ice?

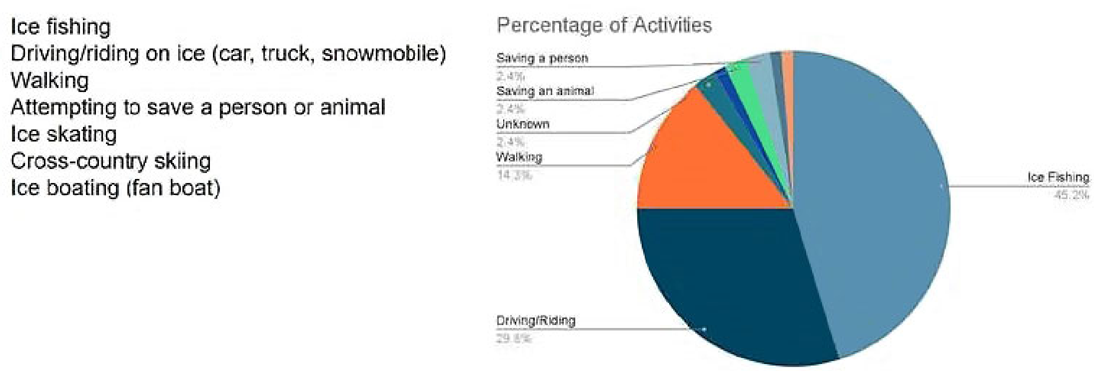

FIGURE 6.5b: Age distribution of those invloved in ice-related and cold water boating rescues or drownings (1990-2023)

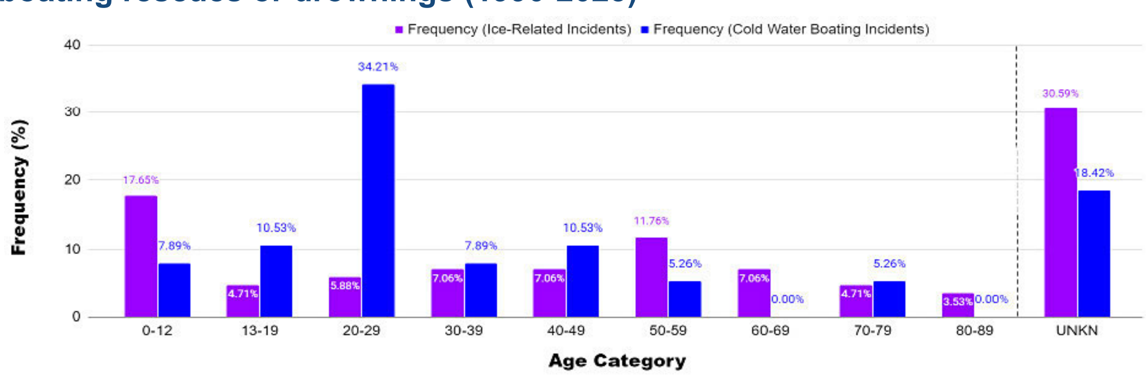

Figure 6.5b: Cold-water boating incidents most frequently involve people in their 20s. Ice-related incidents most frequently involve children (12 and under) and people in their 50s. (Data courtesy the National Weather Service)

13 Betts, A.K. (2011) personal communication.

14 Data courtesy National Weather Service Burlington, Vermont

Key Message 2: Vermonters are exposed to multiple hazards, all of which are complex, changing and interconnected

Across Vermont, natural hazards of varying intensity, duration and frequency occur. These include severe storms, winter storms, drought, flooding, wildfires, air pollution, ground-level ozone, temperature extremes, localized winds, and biotic elements (insects and disease). Some of these hazards are ubiquitous while others tend to occur at specific geographic locations. This poses varying exposure or risk and, therefore, societal vulnerability.

It is unequivocal that climate-related hazards are impacting Vermont with increasing frequency and intensity. The changing seasonality outlined above in Key Message 1 creates compound and cascading effects that strain emergency response systems and affect everyone, but that hit some Vermonters harder than others—like farmers dealing with unpredictable growing seasons, older residents during heatwaves, or manufactured housing communities during floods. Vermont's interconnected natural and human systems mean that impacts to one sector (such as agriculture or infrastructure) create ripple effects throughout communities. While individual extreme events cannot be directly attributed to climate change, the increasing frequency and severity of hazards aligns with scientific projections. These intensifying hazards often lead to increased emissions (when, for example, extreme weather damages infrastructure or forces greater energy use), creating a cycle that requires adaptation strategies to protect communities and mitigation efforts to reduce future impacts. This evolving landscape of hazards demands new approaches to planning that account for changing conditions and help communities become more resilient.

The Vermont Geological Survey (VGS) is at the forefront of this clarion call to action. It wasn't until Vermont was significantly impacted by landslide hazards following extreme precipitation events in July 2023 and July 2024 (Figure 6.3b, 6.3c), both of which resulted in federal disaster declarations, that the VGS more fully realized the state's susceptibility to unstable slopes. As a result of these storms, the VGS has responded to over 150 individual requests for landslide hazard assessments in 64 towns primarily located along the corridors of greatest rainfall, and it has supported Vermont Emergency Management in technical evaluations for 16 residential buyouts through the Federal Emergency Management Agency (FEMA). From these site visits, it has become clear that Vermont's slope susceptibility is not limited to the "typical" glacial stratigraphy associated with landslides, but rather that nearly all unconsolidated materials on slopes become prone to failure over some threshold precipitation amount. Significant failures have been observed on glacial till, lacustrine and fluvial sands, and artificial fill at residential and municipal parcels that hadn't shown signs of failure for decades to centuries.

In terms of socioeconomic vulnerability due to 11 factors (including age, income, mobility, and veteran status), the NOAA Billion-Dollar Weather and Climate Disasters mapping tool (Figure 6.6a) shows that Vermont has an overall vulnerability score of 9.95 compared to the national average of 13.5. However, as noted for weather and climate risks in Key Message 1, socioeconomic vulnerability varies by factor and by county, ranging from the highest values in Essex (11.67), Orleans (11.48) and Bennington counties (10.63) to the lowest in Chittenden (8.98) and Grand Isle (8.89) counties. In most counties, it is the Census tracts with the smallest geographic area that have the largest socioeconomic vulnerabilities. Census Tract 3 in Chittenden County has the largest overall socioeconomic vulnerability in Vermont with a score of 16.29. This tract, which runs along Riverside Avenue and into the Old North End in Burlington, is explored more fully in “The White Monsters and Vulnerability in Burlington’s Intervale” (p. 37). The components that contribute to a community’s resilience are shown in Figure 6.6b.

FIGURE 6.6a: Socioeconomic vulnerabilities.

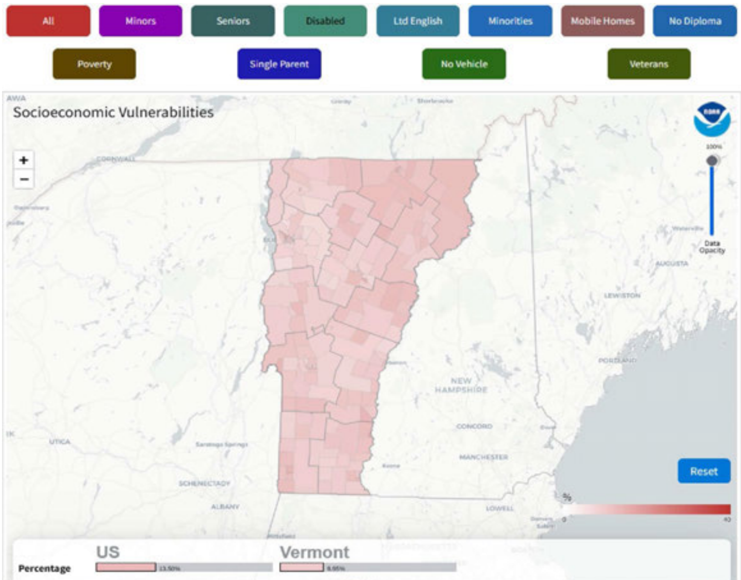

FIGURE 6.6b: Baseline resilience indicators for communities.

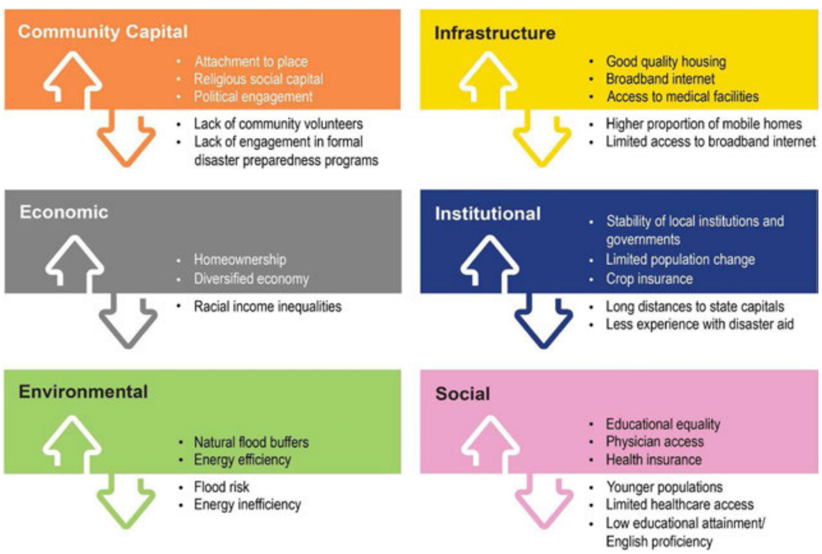

Figure 6.6: (6.6a) Map of Vermont's counties and census tracks showing the degree of socioeconomic vulnerability (0–40) due to 11 factors (NOAA National Centers for Environmental Information (NCEI)).[15] (6.6b) "The Baseline Resilience Indicators for Communities (BRIC) index is a composite measure of community resilience to natural hazards. It considers 49 indicators of existing attributes of resilience arranged in six broad categories: social, infrastructure, institutional, environmental, economic, and community capital. It can be used to compare community resilience within one county to that of another … Positive and negative drivers of resilience for rural counties are provided for each category." –Fifth National Climate Assessment (USDA).

15 NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2025). DOI: 10.25921

The White Monsters and Vulnerability in Burlington's Intervale

by Judy Dow

As a child, I lived in Burlington and my relatives mostly lived near here. I am very familiar with the landslides in the area. The first photo-documented landslide of Riverside Avenue in Burlington was in 1929. Small mudslides continued with at least one or two each decade until 1955 when a major landslide occurred after receiving 2.37" of rain.[16], [17] That event was followed by three smaller mudslides in the same year. After a mudslide in 1958, it took 5,000 cubic yards of rock and other fill (that's a quarter of a football field filled up to the top of the goal posts) to make repairs to the area. Each decade after 1955 witnessed at least two landslides per year in this same area until August 2024 (personal observation).[18] When combined with large amounts of water, a landslide forms a flowing liquid creating a mudflow or mudslide, which has more fluid than a landslide. Here, I have used the terms landslide and mudslide as they have been used by the source.

There seem to be many drivers for these mudslides as excessive rain events continue and the land becomes more and more saturated leading to the landslides. The years of adding fill have contributed to a lack of successful drainage. The slope of the bank is steep and insufficient stabilization has contributed to landslides in this area. The city of Burlington has increased the width of roads and added sidewalks in this area, which have continued to push the buildings further toward the steep banks.[19] In addition, 25 to 37 train carloads of wood chips and approximately 20 18-wheeler truckloads of logs and wood chips travel this road each day on their way to McNeil Generating Station.[20] The weight alone adds pressure on the filled areas.

The parking lots and backyards of the businesses along this road show signs of future mudslides. Increased major precipitation events, cracks everywhere, illegal dumping, and the continued building on unstable land adds to a loss of land and healthy riparian zones, more precarious homes for people, and the loss of connectivity for animals and biodiversity. The future of this area looks tenuous with a serious risk of future mudslides. Predicted increases in storm event frequency and intensity will only exacerbate slope hazards by raising groundwater tables.

16 Traditional Ecological Knowledge.

17 Vermont Agency of Natural Resources GIS – Open Data: Landslides (2018).

18 Triantafillou, S., Morrison, A., Mischler, E. And Debber, J. (2020) Landslides along the Winooski River in Burlington, Vermont: Landscape change and slope stability, Department of Geology, University of Vermont.

19 Triantafillou et al. (2020).

20 Personal interviews with residents.

FIGURE 6.7a: Chittenden County Census tracts.

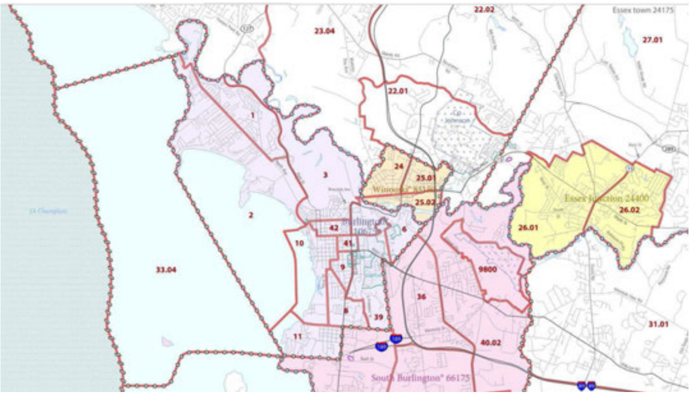

FIGURE 6.7b: Census Tract 3 socioeconomic vulnerabilities.

Data Type	Census Tract 3	Chittenden County	Vermont	U.S.
Age < 18	20.60%	18.20%	19.01%	22.36%
Age 65+	7.20%	14.10%	19.46%	18.37%
All Vulnerabilities %	16.29%	8.98%	9.95%	13.5%
Disabled Population	14.70%	11.60%	15.14%	15.92%
Limited English	8.80%	1.40%	0.36%	1.70%
Minority Population	38.30%	11.20%	5.99%	23.51%
Mobile Homes	--	4.50%	8.01%	12.93%
No High School Diploma	17.40%	5.90%	8.21%	13.41%
Below Poverty	22.80%	11.80%	11.27%	15.60%
Single Parent Households	10.60%	6.80%	7.59%	8.32%
No Vehicle	19.50%	7.30%	6.11%	6.35%
Veterans	3.00%	6.02%	8.32%	8.91%

FIGURE 6.7c: Census Tract 3 weather and climate risk.

Data Type	Census Tract 3	Chittenden County	Vermont	U.S.
Drought Risk	--	--	.36	11.61
Flooding Risk	8.19	5.92	9.13	9.13
Freeze Risk	12.10	11.22	12.45	15.72
Severe Storm Risk	10.22	6.35	6.66	16.99
Tropical Cyclone Risk	6.05	3.15	2.79	4.36
Wildfire Risk	.36	1.45	1.79	6.30
Winter Storm Risk	11.36	11.49	11.44	13.71

FIGURE 6.7d: 1929.

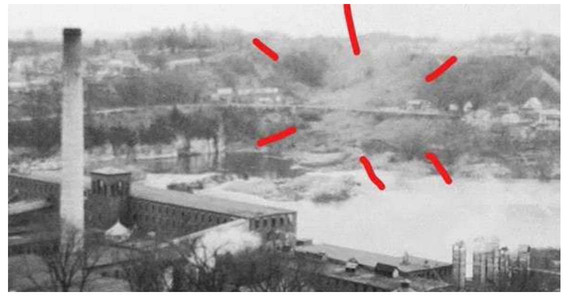

FIGURE 6.7e: 1955.

FIGURE 6.7f: 2020.

Figure 6.7: (6.7a) Spotlight on Census Tract 3 in Burlington, bounded by Riverside Avenue, Route 127 and the Winooski River (United States Census 2020). This Census tract has (6.7b) the highest socioeconomic vulnerabilities in Vermont, (6.7c) is prone to freezing, winter storm and severe storm risks (NOAA National Centers for Environmental Information (NCEI)).[21] It also has experienced (6.7d–f) multiple landslides along Riverside Avenue close to Winooski Intervale, as shown in the photos dating back to 1929 (courtesy Judy Dow).

21 NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2025). DOI: 10.25921

The White Monsters [Listen to the audio narration.]

Pepe lived on the edge of town, high up on the bluff overlooking the Intervale and the Winooski River in a place called Moccasin Village. Moccasin Village was built on the top of an ancient sand dune nestled between the intervale and Lake Champlain. All 20 or so families living in Moccasin Village were French Indian people who had decided to stop traveling back and forth to Canada and settle down in one place; in 1886, Moccasin Village was called home. “Times were changing,” Pepe used to say, but living next to the Intervale was perfect because people could still hunt, fish, and gather off this open land. “Intervale” is an old English word that describes a long narrow valley between two high points with a river running down the middle. To us, it was the common pot, a huge bowl of food. This particular Intervale is called the Winooski Intervale. Burlington, Colchester and Winooski surround the 1,700 acres. Outside of New England, people never use this word to describe the land.

In the spring, when we visited Pepe, we would go to the Intervale to harvest fiddle heads and wild leeks. *Winooski* means “the place of the wild onions” in the Abenaki language. As soon as the snow was gone, the leeks would peek their heads out of the ground. You didn’t need many. They had a strong taste but added a lot of flavor to the roasted squirrel and baked beans that Pepe often had cooking on a small ledge in the wood-fired boiler downstairs in his house.

Pepe would tell me stories as we walked through the riparian forest, picking a few fiddle heads here and a few there until we had a pail full. “It was important not to pick all that we wanted in one place, picking all the heads on one bulb would kill the bulb,” Pepe explained. So, we walked all day long picking here and there. The heads we left behind would provide a beautiful spray of ostrich ferns that would eventually grow to cover the worn path we walked in early spring. As we slowly walked back to the house, I would tell Pepe how much I loved spending time in the Intervale. “Yes,” he would tell me, “it’s a great place to visit and get your food.”

Before I was born, Pepe would hunt for muskrats in the spring; he and my father would tan the hides in their backyard and sell them for 75 cents apiece. Muskrats live in the wetlands of the Intervale, making little push-ups for dens to protect the young from predators. When visiting Pepe during this time, it was not uncommon to see many hides stretched out drying in his backyard. People wanted the hides for their warm coats.

Sometimes in the spring we would fish for shad. When the shad trees were in bloom in the uplands where I live, the shad were spawning in the lowlands, where

Pepe lived. Pepe would go to the edge of the river where his two-ended boat was tied up, and we would fish for shad. The pesky little shad flies were out too, and they would land on every part of my body until I shooed them away. Pepe would say, “Never mind them. They won’t hurt you. They are food for the fish.” This cycle is confused now because of climate change. The shad flies are not always there in time for the shad run. My favorite berries were shadberries. We would pick baskets full of these little berries and bring them to Pepe because they didn’t grow in the Intervale and Pepe loved them. As we floated down river in the boat that Pepe’s brother had made, I looked up at the trees stretched out over the river and I dreamed of living in the Intervale. I never wanted to leave there, it was so beautiful.

In the summer, we made many trips to the intervale, picking raspberries, blackberries, and many different kinds of plants for food and medicines. We also fished for bass and perch and occasionally caught an eel. Pepe had stories for all of them. I can still hear him singing, “Little fishes in the lake come and bite upon my bait.” The eels were sweet and prized by the elders living down the road, so Pepe nailed their heads to the tree, cut around their throats, and pulled the skins off. He then had us deliver the eels to the old people living in Moccasin Village. I later found out that eels have a high nutritional value, something I’m sure Pepe knew all the time. That’s why the old ones got the eels.

When fall came, things were different. We went to the Intervale to gather butternuts. We would pick bushels of butternuts. Filling our backpacks with the heavy nuts, we would lug them back to Pepe’s house. We would place newspapers on the floor in the basement and spread the nuts out to dry. When it got cold outside, Pepe would slide the nuts into a vice that was anchored to his work bench and crack them open, one by one. He would place the special nut meat into canning jars and for Christmas everyone got a jar to celebrate the holiday. It was the greatest treasure to receive, and we were excited because with the nuts in hand we knew that my father always made penuche fudge.

It was in the fall that Pepe would hunt for deer, ducks and geese. His freezer was always full of frozen game and the pantry filled with canned fruit and vegetables. We grew plums, apples, pears and berries. Along with the harvest of our vegetable garden, we always had some awesome food come winter. Pepe made some of the most wonderful meals I ever had; the food he harvested from the Intervale was different than what we get at the grocery store today. In most grocery stores you can’t find venison, duck, goose and squirrel at the meat counter, or butternuts and fiddleheads on the shelves, but you could find them in the freezer and on the shelves at Pepe’s. Pepe knew the land. He knew when the fish were spawning, the ducks were migrating, and the deer were yarding up.

He knew when to burn the Intervale and where the burning was most beneficial for drawing out the muskrat in the spring. Pepe understood the cycles.

As soon as the ice froze in the flooded parts of the Intervale, we would be out there skating and sliding down the side of the 30-foot bluff into the Intervale. When the ice was frozen enough to walk on, Pepe would say, “It is time to burn the Intervale,” and my father and other neighborhood kids would gather to each light certain parts of the land on fire. This was often reported in the local papers as mischievous kids playing with matches. The wetland plants that once stood green and tall were frozen, brown and brittle now from the cold, and when touched by the fire they curled up and burned to little piles of ash that blew away in the wind. Pepe said, “The burning brings new plants in the spring like the cattails, sedges and arrowhead that the muskrats love to eat.” Then the cycle would continue, and Pepe would have more muskrat to harvest in the spring.

One beautiful winter day when we were snowshoeing through the Intervale, I blurted out, “Pepe, I love the Intervale. I want to live here when I grow up.” “You can’t live in the Intervale,” he said. “Why?” I asked. He then told me, “Not always, but sometimes the White Monsters come and destroy everything in the Intervale.” “The White Monsters,” I gasped. He said, “The Intervale is a place that we have to share with the White Monsters. It is their home, too. The White Monsters are what help to make the Intervale so special,” Pepe said. Slowly, we walked back to his house, and he told me the story of the White Monsters.

Pepe explained that the Intervale was a place that was supposed to receive excess water during times of flooding. “Flooding is important to the cycle of life,” he told me. “Flooding brings nutrients from upriver and spreads it all over the Intervale. The nutrients help the plants and animals to grow, and then help us by providing the plants and animals that we eat.” “But, Pepe, what are the White Monsters?” I asked. “The White Monsters are the big chunks of ice that float in the high water onto the Intervale floor. They often tear down buildings, houses, trees and bridges on their way to the Intervale. They are so big, sometimes they destroy everything in their way, and that’s why you can’t live in the Intervale. You just never know when they are coming. People should live high up on the bluffs and visit the Intervale, but they shouldn’t live there unless they are prepared to lose everything they worked hard for.”

I was sad thinking about not being able to live in the Intervale, but I understood what Pepe was telling me. Sharing the Intervale with the White Monsters was not so bad because I still got to visit during the times they weren’t there. On their occasional visits, I would be sure to greet them from high on the bluffs overlooking the Intervale, just as my ancestors had done before me.”

Key Message 3: Climate change increases challenges for Vermont's most vulnerable peoples

The impact of climate change on the health of Vermonters is covered in depth in Chapter 7, Understanding the Indirect Impacts of Climate Change on Human Health and Wellbeing in Vermont. This Key Message provides a preview of how climate change impacts Vermont's most vulnerable communities. Vermont is at risk of loss and destruction of some of its most sacred places. Increasing heatwaves create serious health risks, especially for older adults, children, outdoor workers, and those without air conditioning. These rising temperatures bring cascading effects: worse air quality, more disease-carrying ticks and mosquitoes, and harmful algae blooms in our lakes and ponds. More frequent and severe flooding threatens not just homes but entire communities, leading to displacement and long-term health issues from mold and moisture damage. This is especially true for manufactured homes, which have suffered disproportionate damage in past floods despite making up a small portion of Vermont's housing (Figure 6.8). When extreme weather knocks out power, it creates dangerous situations that disrupt communications and particularly affect rural residents and those who rely on electric medical equipment or may need access to emergency services. These impacts hit hardest in lower-income communities, where affordable housing often faces greater exposure to floods and storms. The loss of culturally significant and sacred places adds another profound dimension to these challenges, affecting community identity and wellbeing.

FIGURE 6.8a: Manufactured housing communities.

FIGURE 6.8b: Summary of vulnerability by level of scale in manufactured housing communities.

MHC scale	Common observations from Vermont MHC fooding events
Household level	Households with limited financial resources
Household level	Older adults (65+ years or older)
Household level	Pre-existing health or mobility concerns
Household level	Households needing to remain close to employment, education, and other critical community resources
Housing structure level	Housing units unable to be feasibly repaired from flooding damages
Housing structure level	Older units contained hazardous materials
Housing structure level	Lack of homes properly elevated and anchored
Community level	Parks sited in FEMA-mapped floodways, 100-year and 5—year floodplains
Community level	Aging infrastructure concerns
Community level	Threat of whole community displacement
Community level	Challenges with finding temporary and permanent housing alternatives

Figure 6.8: (6.8a) Location of manufactured housing communities across Vermont (Baker et al. 2014).[22] (6.8b) Social vulnerabilities experienced at the household, building and community scales in the wake of flooding events (Hamshaw and Baker 2024).[23]

Key Message 4: From farms to Main Street, Vermont's changing climate impacts all communities

Vermont's working landscape and community systems face mounting pressures from climate change. Mora et al. (2018) found over 400 pathways by which multiple sectors, including human health, security, food and water, infrastructure and economy, have been impacted by hazards such as flooding, heatwaves, changes in natural land cover, fires and

22 Baker, Daniel & Hamshaw, Scott & Hamshaw, Kelly. (2014). Rapid Flood Exposure Assessment of Vermont Mobile Home Parks Following Tropical Storm Irene. Natural Hazards Review. 15. 27-37. 10.1061/(ASCE)NH.1527-6996.0000112.

23 Hamshaw KA, Baker D. Manufactured housing communities and climate change: Understanding key vulnerabilities and recommendations for emergency managers. J Emerg Manag. 2024 Special Issue on Climate Change and Sustainability in Emergency Management;22(7):87-99. DOI: 10.5055/jem.0845. PMID: 38573732.

others.[24] In Vermont, our iconic dairy farms and maple sugaring industries struggle with warmer winters and heatwaves affecting everything from milk production and livestock stress to maple sap flows, damaged sugar maples, and losses in overall farm productivity. Vermont's buildings and transportation systems, originally designed for cold, temperate climates, face increased strain due to higher temperatures. Roads, bridges and railways risk damage from thermal expansion, and the Urban Heat Island effect exacerbates heat exposure in cities.

Many of our historic downtowns, built along rivers that once powered mills, now face increased risks from fluvial erosion and damage. When severe weather interrupts power supplies, it creates a domino effect—particularly dangerous for healthcare facilities trying to keep patients comfortable and safe. Local businesses are feeling the squeeze, too. Weather-damaged inventory, structural losses, and disrupted supply chains and deliveries cut into their bottom lines. Towns and state agencies spend more on snow removal while also maintaining and repairing deteriorating infrastructure impacted by freeze-thaw cycles exacerbated by climate change.

The ski and tourism industries face growing challenges as warming winters reduce the amount of natural snowfall, shortening seasons and producing an increasing reliance on expensive artificial snowmaking.

Increased rainfall and snowmelt, linked to climate change, contribute to slope instability, exacerbating the risk of landslides. Human activities, like infrastructure construction, can worsen this risk by improperly managing surface runoff or by overloading slopes. Roads, bridges, culverts and buildings on or near steep slopes, especially in areas affected historically, are vulnerable to landslide damage. Landslides can severely impact recreational spaces, such as hiking trails, and hinder transportation networks, thereby complicating emergency response efforts.

Although wildfires are currently rare in Vermont, increased temperatures, low humidities, high daily temperatures and various types of droughts have the potential to increase the incidence and exposure to wildfire risks. Severe air quality concerns arose in the summer of 2023 as the wildland fires burning in the boreal forests of northern Quebec reached Vermont. Wildland fire smoke, from the western U.S. and other parts of Canada, typically produce fewer visibility and human health challenges because it is being transported higher in the atmosphere.

24 Mora, Camilo, Daniele Spirandelli, Erik C. Franklin, John Lynham, Michael B. Kantar, Wendy Miles, Charlotte Z. Smith, et al. 2018. "Broad Threat to Humanity from Cumulative Climate Hazards Intensified by Greenhouse Gas Emissions." Nature Climate Change 8 (12): 1062–71.

Key Message 5: The integrity of Vermont's ecosystems is in peril

Expected changes to Vermont's climate that have been identified in other parts of this plan will profoundly affect the natural resources and ecosystems that we enjoy and upon which we depend. Rustad et al. (2014) reviewed literature on how climate change is changing the structure and function of the forest ecosystems in the northeast. While slow change in forest composition is normal, observed changes in temperature, precipitation and snowfall are rapidly changing our forests (Figure 6.9a, b). The tree species that grow in our forests strongly influence the way that water and essential nutrients move through ecosystems. Changes in meteorological variables also alter the habitat characteristics and food types that determine the species of insects, birds and animals that are likely to flourish in these environments. For example, birds are one of the best studied organisms in the northeast. Rustad et al. (2014) concluded that there is strong evidence for a northward expansion of bird species that were once found further south, often at the expense of valued native species (Figure 6.9c).[25] Climate change also brings the threat of nuisance species that can affect the health of forest tree species (Figure 6.9d). Hemlock woolly adelgid has already infected hemlock stands in the southern parts of the state and is moving northward. As the climate warms, other pathogens like Armillaria root rot may begin to infect tree species that are being stressed by climate change.

Potential impacts of climate change are not restricted to terrestrial ecosystems. For example, Sievert et al. (2022) identified "classes" of fish communities in the northeast and midwest on the basis of in-stream temperature and flow characteristics combined with landscape, environmental and climate variables, concluding that throughout most of Vermont, fish species were at "high" to "very high" risk of changing from one class to another, favoring warm-water tolerant species and disfavoring cold-water tolerant species (Figure 6.9e).[26] These class changes are potentially important considerations for fish biodiversity and recreation management. Finally, there are interactions between land ecosystems and water ecosystems that will be affected by climate change.

Data summarized by the Lake Champlain Basin Program show how major storm events, like the July 2023 flood, can deliver not only high runoff totals, but tremendous amounts of sediment and phosphorus as well (Figure 6.9f).[27] The July 2023 event delivered more than 100 metric tons of total phosphorus on July 11 alone and 300 metric tons of

25 Rustad, L., J. Campbell, J. S. Dukes, T. Huntington, K. F. Lambert, J. Mohan, and N. Rodenhouse. 2014. Changing Climate, Changing Forests: The Impacts of Climate Change on Forests of the Northeastern United States and Eastern Canada. Pages 50. General Technical Report NRS-99. U.S.D.A. Forest Service, Newton Square, PA.

26 Sievert, N., C. Paukert, J. Whittier, W. Daniel, D. Infante, and J. Stewart. 2022. Projected stream fish community risk to climate impacts in the Northeastern and Midwestern United States. Ecological Indicators 144:109493.

27 Lake Champlain Basin Program. 2024. State of the Lake Report 2024. Lake Champlain Basin Program, Grand Isle, VT.

phosphorus from July 10–16, which represented half of the recommended total annual load of phosphorus to Lake Champlain. Other water bodies in Vermont were affected in similar ways by this and other events. Such events hinder our ability to meet water quality targets and threaten indigenous aquatic species that we value.

FIGURE 6.9a: Projected changes in habitat for 12 tree species.

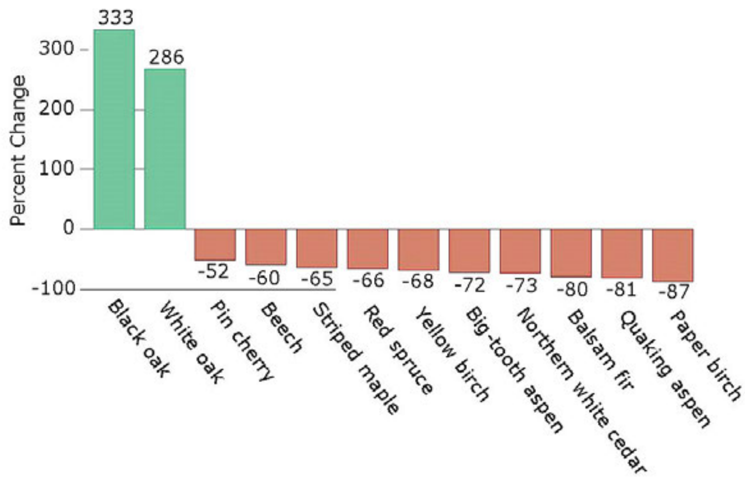

Figure 6.9a: The 12 tree species showing the largest projected changes in suitable habitat in 2100 under an average-high emissions scenario. The emission scenarios used in this and other panels in this figure are based on the Intergovernmental Panel on Climate Change (IPPC 2007) greenhouse gas emissions scenarios for New England forests 2000–2100. The emissions scenarios cited in these figures refer to older terminology but can still be interpreted as “low” and “high.”

FIGURE 6.9b: Current and projected suitable habitat for New England forest types.

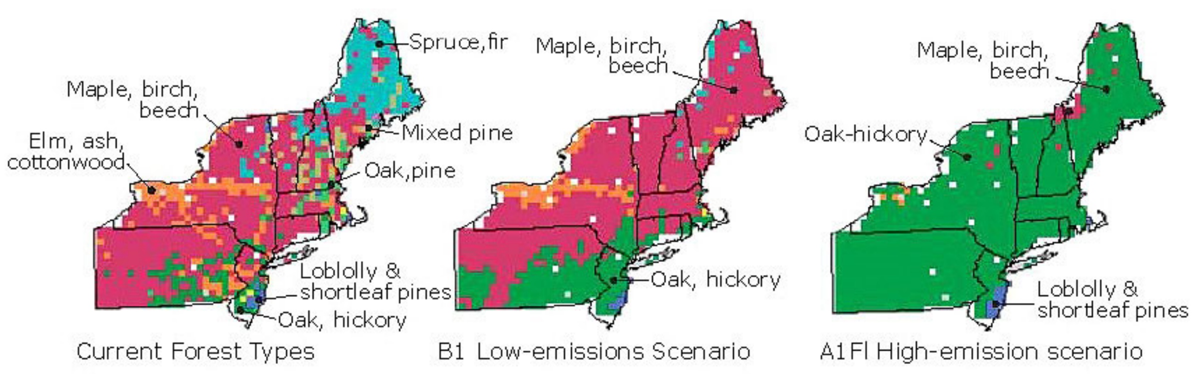

Figure 6.9b: Current and projected suitable habitat for major forest types in New England under low-and high-emissions scenarios. Under the low-emissions scenario, the conditions will favor maple-birch-beech forests, while the high-emissions scenario suggests that conditions will favor oak-hickory forests.

FIGURE 6.9c: Bird species projected to change abundance and range.

Scenario	Abundance declining	Abundance unchanged	Abundance increasing	Range declining	Range unchanged	Range increasing
Low emissions (B1)	60	22	68	33	60	57
Average-high (A2)	56	27	67	32	62	56
High emissions (A1FI)	38	48	48	15	94	41

Figure 6.9c: Number of bird species projected to change their abundance and range 2000–2100.

FIGURE 6.9d: Modeled responses of six nuisance species to climate warming.

	Range	Impact	Confidence
Hemlock woolly adelgid	+	+	high
Tent caterpillar	+ or 0	unknown	medium
Root rot	0	+	medium
Beech bark disease	+	unknown	medium
Oriental bittersweet	+	0	low
Glossy buckthorn	0	0	low

Figure 6.9d: Modeled responses of six nuisance species to climate warming where impact refers to the severity of impact within the three species range. (Figures 6.9a-d: Rustad et al.)[28]

FIGURE 6.9e: Risk of fish community change due to predicted changes in climate.

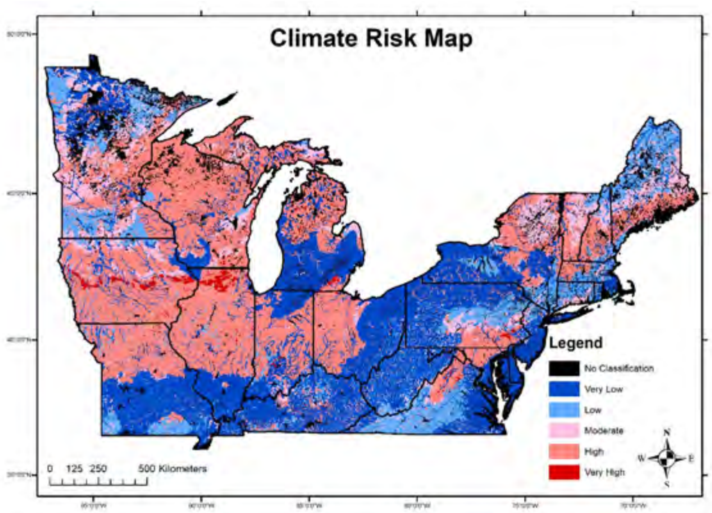

Figure 6.9e: Map showing relative risk of fish community change due to predicted changes in climate. Areas that are not classified are typically reservoirs, lakes, or wetlands for which the local catchment does not include an associated river or stream segment. (Sievert et al. 2022).[29]

28 Rustad et al. (2014)

29 Sievert et al. (2022)

FIGURE 6.9f: Cumulative river phosphorus loading to Main Lake segment of Lake Champlain.

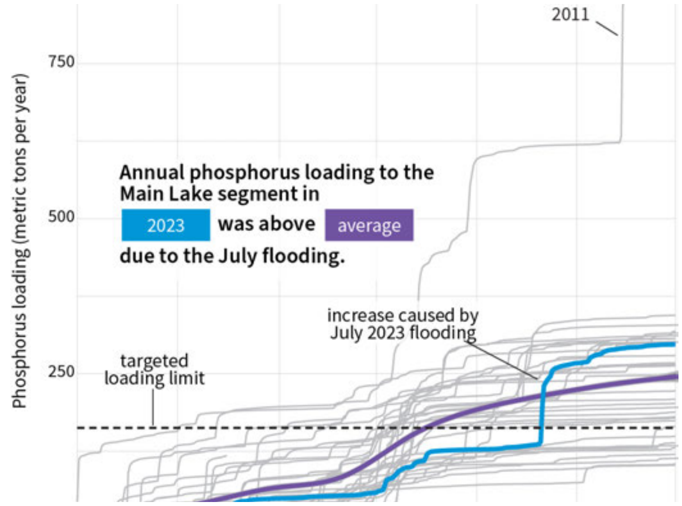

Figure 6.9f: Cumulative river phosphorus loading to the Main Lake segment of Lake Champlain, each year since 1991. Water years are shown, starting on October 1 and ending on September 30. Data sources include the Lake Champlain Long-Term Monitoring Program (Lake Champlain Basin Program, Vermont Agency of Natural Resources, State University of New York Plattsburgh) and USGS, from the Lake Champlain Basin Program (2024).

FIGURE 6.9g: July 2023 flooding by the numbers.

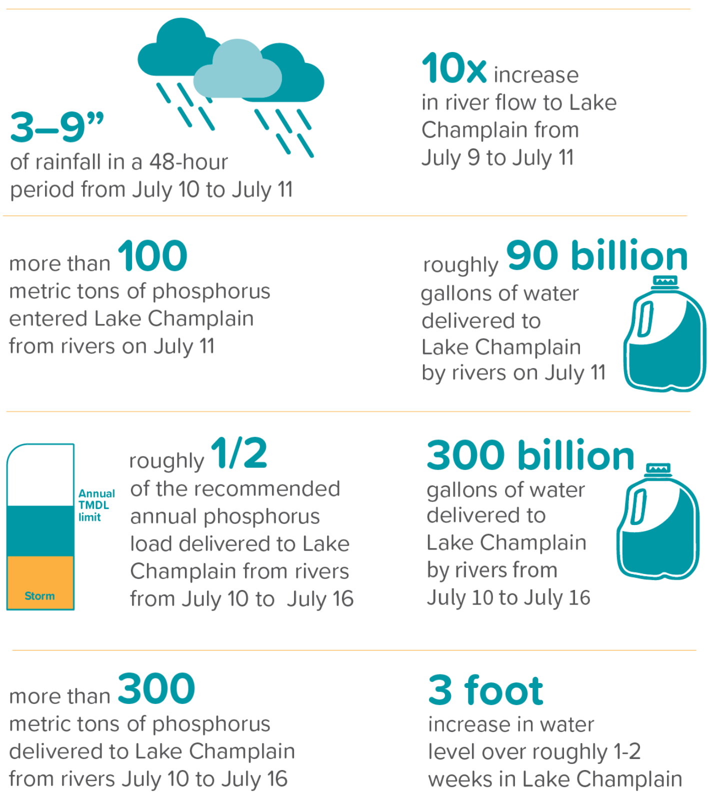

Figure 6.9g: July 2023 flooding impacts by the numbers from the Lake Champlain Basin Program (2024).

Key Message 6: There are critical knowledge gaps in the current research about Vermont's climate and climate change; opportunities also exist

Several important areas of Vermont's climate and climate change impacts remain understudied, limiting our ability to fully understand and address emerging challenges. One significant gap involves tracking and quantifying climate migration and displacement. Such monitoring and analyses should be centered on the Earth Systems Science approach of the 2024 National Academies report on this topic, in order to facilitate for a more rigorous understanding of a) the temporary and permanent movement of Vermonters as well as in-migration to Vermont as a result of climate-related hazards and impacts, b) the ability of displaced communities to adapt, and c) disparities that may exist or be exacerbated.[30] We also lack comprehensive data correlating climate change with shifts in agricultural production and its ripple effects through rural communities. In terms of public health, more research is needed to understand how declining groundwater levels may concentrate contaminants, particularly affecting Vermonters who rely on well water. There are also crucial gaps in our understanding of how gradual climate changes affect affordable housing. For instance, while we have anecdotal evidence that reduced snowpack around manufactured homes leads to moisture damage and health risks (historically, this snow provided crucial insulation), we lack systematic studies of these impacts. These knowledge gaps highlight the need for more focused research to better protect vulnerable communities and inform adaptation strategies.

Despite the climate change challenges we face, action is possible. In addition to the recommendations and pathways to reduce the state's greenhouse gas emissions profile detailed in this plan, opportunities exist to build upon existing programs and maximize co-benefits among clean water, biodiversity, and climate resilience in the state. For example, Vermont can advance flood mitigation, climate adaptation, and resilience through riparian, wetland and floodplain conservation and restoration. Priority recommendations in this plan highlight the need to adapt land management practices to increase ecosystem resilience, enhance biological diversity, improve water quality, and identify sources of funding for climate resilience adaptation practices that increase the financial capacity of land and water caretakers to achieve these goals. The plan also recommends the promotion of healthy, connected river corridors, floodplains and wetlands through expansion of wetlands, floodplains, riparian forests and/or river corridor easements that support co-benefits of increased resilience to climate change, enhanced biological diversity, and water quality benefits. These nature-based, cost-effective

30 National Academies of Sciences, Engineering, and Medicine. 2024. Climate Change and Human Migration: An Earth Systems Science Perspective: Proceedings of a Workshop. Washington, DC: The National Academies Press.

approaches increase the resilience of natural and human communities to future flooding and droughts. The effect of the floodplain wetlands in the Otter Creek watershed on maximum flood heights in Middlebury during Tropical Storm Irene in 2011 is particularly telling.[31] It is estimated that these wetlands reduced the potential damage to Middlebury by at least six times and perhaps as much as 20 times.[32] The long-term benefit of these nature-based solutions is compelling. Other initiatives like strategic dam removals, right-sizing culverts, and innovative agricultural and land-use practices can create connectivity that enhances aquatic organism passage and reduces runoff of sediment and phosphorus that negatively impacts our water bodies. We can also support funding that will help agricultural producers continue to provide a vibrant local food system while at the same time addressing our climate and water quality goals on working lands. We can support improvements to public infrastructure, including bridges, roadways, drinking water facilities, waste treatment facilities, individual septic systems, and stormwater infrastructure, to meet current codes and standards and withstand future flooding events. We can prioritize land use and sustainable development that reduces water quality impacts through consistent regulatory enforcement and with support, resources, and technical assistance for developers, farmers and woodland owners to ensure sound management, healthy soils and clean water.

Key Message 7: How is our climate projected to change in the future?

A warming and wetter climate has varying effects on different weather and climate hazards (Figure 6.10a). Projected changes in temperature through 2050 show a high degree of confidence in temperatures increasing, resulting in a higher frequency of warmer temperatures and heatwaves. In northwestern Vermont, by the end of the century, temperatures over 86°F are projected to increase by at least 27 days under the low-emissions scenario and by as much as 57 days under the high-emissions scenario (Figure 6.10b). On the other hand, the most extreme cold temperatures will likely decline in magnitude slightly as arctic warming tends to diminish the strength of wintertime arctic air masses. Overall annual precipitation will likely increase, although at a slower rate than temperature (moderate confidence). Extreme precipitation events, such as those with 2” or greater precipitation in a 24-hour period, will likely increase in frequency (moderate confidence).

31 Galford, G., A. Hoogenboom, S. Ford, J. Nash, E. Palchak, S. Pears, K. Underwood, and D. Baker. 2014. Vermont Climate Assessment: Considering Vermont’s Future in a Changing Climate. Gund Institute of Ecological Economics, University of Vermont, Burlington, VT.

32 Watson, K. B., T. Ricketts, G. Galford, S. Polasky, and J. O’Niel-Dunne. 2016. Quantifying flood mitigation services: The economic value of Otter Creek wetlands and floodplains to Middlebury, VT. Ecological Economics 130:16-24.

FIGURE 6.10a: Vermont climate projections: hazard risks (2020–2050).

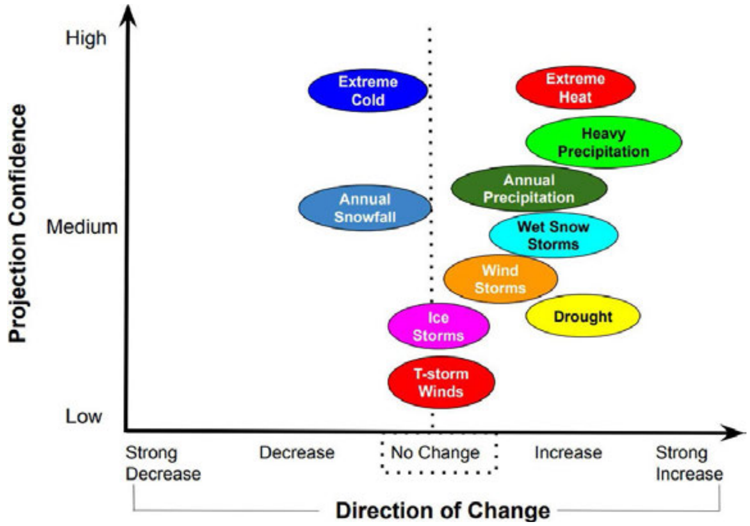

FIGURE 6.10b: Vermont temperature trend and climate projections.

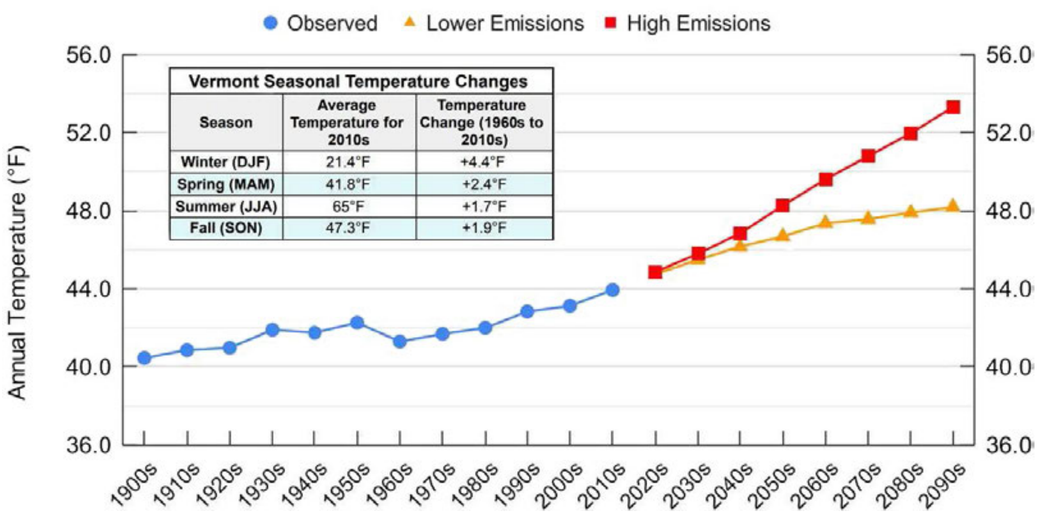

Figure 6.10: (6.10a) Projections of natural hazards in Vermont with their corresponding confidence levels (Shafer and Cronin 2021)[33]; (6.10b) Vermont decadal temperature observations and projections under the low-emissions scenario (RCP4.5 - moderate global GHG emissions mitigation) and the high-emissions scenario (RCP8.5 - GHG emissions continue following business as usual). Inset table shows current and observed seasonal temperature changes across Vermont. Source: Both the inset table and observed temperatures graphic were created using climate division data downloaded from NOAA's National Centers for Environmental Information, Climate at a Glance tool; climate projections data (red and orange lines) were downloaded (at the county scale and aggregated to a statewide value) from NOAA's Climate Explorer tool. Further details on this figure can be found on Figure 7a of the Initial Climate Action Plan 2021.

33 Shafer, J. C., and K. Cronin, 2021: Extreme weather and climate change in Vermont: Implications for the electric grid. Vermont Electric Power Company. 47 pp.

Annual snowfall variability will likely remain high, with some wet winter seasons producing higher than average snowfall, as the climate remains cold enough to continue to support snowfall. However, the general trend is for more winter rain and reduced annual snowfall, especially in lower elevations and southern areas. Risks from power outages related to wet snowfall are expected to increase, as more winter storms will likely be closer to the freezing mark where snowfall is wet or sticky in nature (moderate confidence).

Windstorms are expected to increase in intensity, but these will likely be related to unique meteorological storm types. Tropical storms or hurricanes, if they make landfall and move inland, will likely be able to maintain strength at higher latitudes from warming ocean temperatures, therefore increasing the risk for low-frequency but catastrophic storm impacts (e.g., the Hurricane of 1938). On the other hand, gradient wind events from midlatitude storm systems across Canada or nor'easters may decline in frequency.

The projected frequency of ice storms and thunderstorms remain of low confidence with competing meteorological risk factors for each. Low-end freezing rain icing events (those with ice accretion insufficient to produce power outages) are expected to increase, as warmer winter temperatures produce more winter storms with mixed precipitation types.

Overall risks to the power distribution grid have been shown to be increasing more due to storm systems becoming more intense. A combination of current trends, literature, and two climate simulations shows that overall power outage risks are projected to increase by approximately 5%–10% through 2050, due to more frequent wet snowfall and potentially stronger windstorms.

Vermont's annual precipitation is projected to increase 1" to 2" through 2050. These rates of increase track closely to current precipitation rate changes over the last 30 to 40 years. Through 2100, the low-emissions scenario predicts approximately 4" greater annual precipitation, whereas the high-emissions scenario predicts 9" greater annual precipitation. The spatial distribution of precipitation change is relatively equal across Vermont counties. Extreme precipitation events will increase at a faster rate than annual precipitation increases, likely following current ratios of extreme events to annual precipitation rate changes.

Vermont's annual temperatures are projected to increase over 2°F through 2050 on either the low-emissions and high-emissions scenarios. These scenarios differ significantly through 2100, with the low-emissions scenario predicting 4°F of warming and the high-emissions scenario predicting 9°F of warming. The spatial distribution of warming is relatively equal across Vermont counties. With a warming climate comes a greater likelihood of higher temperatures. Extreme temperatures (as defined by a high temperature >= 90°F) are projected to double in frequency by 2050 through either the low-emissions and high-emissions scenarios. Vermont-wide average days above 90°F go from four days a year to nine days a year by 2050. By 2100, however, there is significant variability, with the low-emissions scenario reaching 15 days a year and the high-emissions scenario projecting 45 days a year.

In terms of hydrology, a high-level picture of Vermont's future in the middle of the twenty-first century has been extracted from the Fifth National Climate Assessment.[34] Figure 6.11 shows relative changes in precipitation, evapotranspiration, snow water equivalent, summer soil moisture, and runoff across the USA. The larger maps show the average expectation, while the smaller maps show the expectations for the wettest 20% of model projections (top) and the driest 20% of model projections (bottom).

34 Payton, E.A., A.O. Pinson, T. Asefa, L.E. Condon, L.-A.L. Dupigny-Giroux, B.L. Harding, J. Kiang, D.H. Lee, S.A. McAfee, J.M. Pflug, I. Rangwala, H.J. Tanana, and D.B. Wright, 2023: Ch. 4. Water. In: Fifth National Climate Assessment. Crimmins, A.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA.

FIGURE 6.11a: Projected changes in average summer (June–August) soil moisture by mid-century.

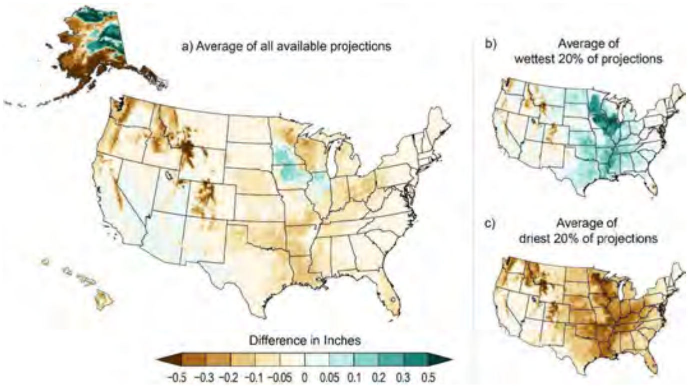

FIGURE 6.11c: Projected changes in maximum annual snow water equivalent by mid-century.

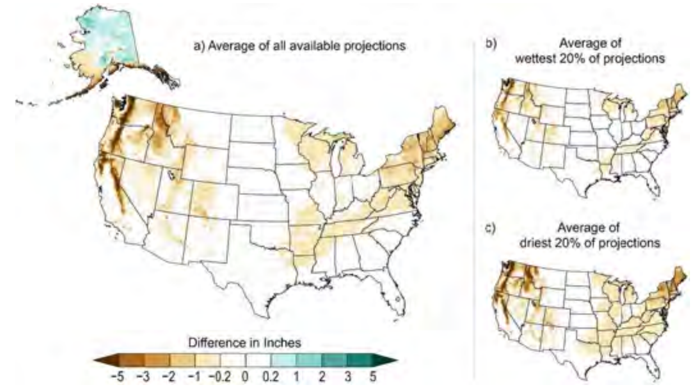

FIGURE 6.11b: Projected changes in annual precipitation by mid-century.

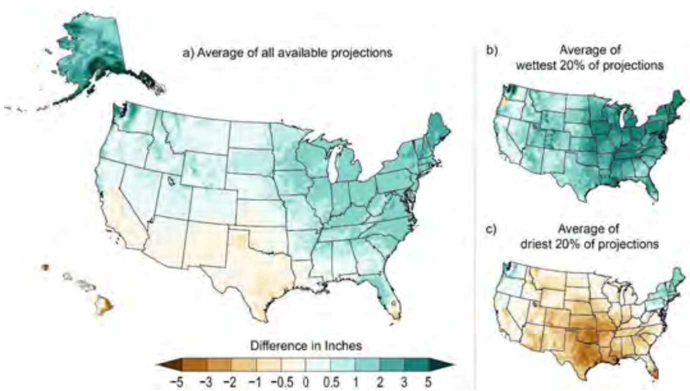

FIGURE 6.11d: Projected changes in annual actual evapotranspiration by mid-century.

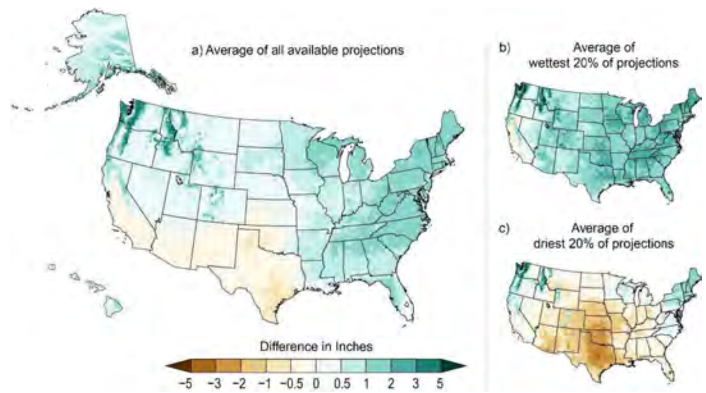

Figure 6.11: Predicted changes in key components of the U.S. water cycle between a reference period (1991–2020) and the middle of this century (2036–2065). (6.11a–d) In each figure the larger map on the left shows the average of all ensemble model runs. For comparison, the two smaller maps on the right show the predictions for the wettest 20% of projections and the driest 20% of projections (Payton et al 2023).[35]

---

35 Payton, E.A., A.O. Pinson, T. Asefa, L.E. Condon, L.-A.L. Dupigny-Giroux, B.L. Harding, J. Kiang, D.H. Lee, S.A. McAfee, J.M. Pflug, I. Rangwala, H.J. Tanana, and D.B. Wright, 2023: Ch. 4. Water. In: Fifth National Climate Assessment. Crimmins, A.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA.

Focusing on Vermont, the following patterns emerge. On average we can expect 1” to 2” of additional rainfall annually. However, we can expect about 1” less total water input from snowfall. A portion of this water coming into the state will be lost back to the atmosphere by evapotranspiration. The model projections suggest that, on average, the additional loss from evapotranspiration will be about 1”. The balance of rain and snowfall that does not undergo evapotranspiration will either soak into the soil or become runoff into surface water bodies. The expectation is that soil will become slightly drier (up to -0.05”). So, the sum of these water gains and losses suggests that future runoff to streams on an annual basis may not change that much, ranging from about -0.1” to about +0.1”. However, as explained in other parts of this report, this very simple water balance formulation obscures crucial changes to the natural ecosystems and human communities that we value and on which we depend. For example, changes in snowfall and soil moisture content, though seemingly small, will have profound effects on the biodiversity of our forest ecosystems and productivity of our working lands. And although the expected increase in rainfall seems small, it is the erratic frequency and increasing intensity of this rainfall that will lead to threats of future flooding if left unmanaged. Floods also impact greenhouse gas emissions by increasing emissions of carbon dioxide and methane from agricultural streams, especially during periods of frequent and prolonged flooding during the growing season.[(36)]

36 Blackburn, S.R. and E.H. Stanley. 2021. Floods increase carbon dioxide and methane fluxes in agricultural streams. Freshwater Biology 66:62-77.