4-3: Wind

Hazard Impacts	Probability	Potential Impact					Score*:
		Infrastructure	Life	Economy	Environment	Average:	
Wind	4	2	2	1	1	1.5	6

*Score = Probability x Average Potential Impact

High wind can be the result of any of the following:

- **Wind Storm:** high wind event without precipitation.
- **Hurricanes/Tropical Storms:** the most significant impacts from hurricanes/tropical storms in Vermont are inundation flooding and fluvial erosion (see: Inundation Flooding & Fluvial Erosion). Wind implications of hurricanes/tropical storms are addressed below.
- **Thunderstorm:** high wind event with the potential for compounding impacts due to precipitation (see: Inundation Flooding & Fluvial Erosion), lightning (see: Wildfire), and/or hail (see: Hail).
- **Tornado:** a violently rotating column of air extending from a thunderstorm; not common in Vermont.

Table 31: Beaufort Wind Scale

Force	Wind (mph)	WMO Classification	Appearance of Wind Effects	
			On the Water	On Land
0	< 1	Calm	Sea surface smooth and mirror-like	Calm, smoke rises vertically
1	1-3	Light Air	Scaly ripples, no foam crests	Smoke drift indicates wind direction, still wind vanes
2	4-7	Light Breeze	Small wavelets, crests glassy, no breaking	Wind felt on face, leaves rustle, vanes begin to move
3	8-12	Gentle Breeze	Large wavelets, crests begin to break, scattered whitecaps	Leaves and small twigs constantly moving, light flags extended
4	13-18	Moderate Breeze	Small waves 1-4ft becoming longer, numerous whitecaps	Dust, leaves, and loose paper lifted, small tree branches move
5	19-24	Fresh Breeze	Moderate waves 4-8ft taking longer form, many whitecaps, some spray	Small trees in leaf begin to sway
6	25-31	Strong Breeze	Larger waves 8-13ft, whitecaps common, more spray	Larger tree branches moving, whistling in wires
7	32-38	Neal Gale	Sea heaps up, waves 13-19ft, white foam streaks off breakers	Whole trees moving, resistance felt walking against wind
8	39-46	Gale	Moderately high (18-25ft) waves of greater length, edges of crests begin to break into spindrift, foam blown in streaks	Twigs breaking off trees, generally impedes progress
9	47-54	Strong Gale	High waves (23-32ft), sea begins to roll, dense streaks of foam, spray may reduce visibility	Slight structural damage occurs, slate blows off roofs
10	55-63	Storm	Very high waves (29-41ft) with overhanging crests, sea white with densely blown foam, heavy rolling, lowered visibility	Seldom experienced on land, trees broken or uprooted, considerable structural damage
11	64-72	Violent Storm	Exceptionally high (37-52ft) waves, foam patches cover sea, visibility more reduced	Very rarely experienced on land, accompanied by widespread damage
12	73+	Hurricane	Air filled with foam, waves over 45ft, sea completely white with driving spray, visibility greatly reduced	Devastation

Source: http://www.spc.noaa.gov/faq/tornado/beaufort.html

Damages following a significant wind storm that hit western Vermont in 2017. *Photo Credit: Burlington Free Press*

Wind Storm:

High winds pose a threat to the safety of Vermont's citizens and property. The National Weather Service (NWS) issues a wind advisory when winds are sustained at 31 to 39 mph for at least one hour or any gusts 46 to 57 mph. Sustained winds of 40 to 73 mph or gusts of 58 mph or higher cause the NWS to issue a High Wind Warning[1].

Hurricane/Tropical Storm:

A hurricane is a tropical cyclone with sustained winds that have reached speeds of 74 mph or higher. A storm reaches hurricane status only after strengthening over a period of days or even weeks. A tropical storm has a maximum sustained one-minute wind speed of 39 to 73 mph. As a hurricane moves toward the coast, it loses wind speed and may be downgraded to a tropical storm. This is the case in many of the tropical storms that have reached Vermont. In general, severe hurricanes are not considered likely, nor do they pose a recurring threat for Vermont.

Hurricanes and tropical storms are hazard events that often result in high winds, inundation flooding, and fluvial erosion impacts. The topography and landscape in Vermont contribute to the risk associated with these three hazard impacts. Many of Vermont's villages, towns and cities are located in or proximate to the floodplain and many roads in Vermont run parallel to rivers (see: Inundation Flooding & Fluvial Erosion).

The Saffir-Simpson Hurricane Wind Scale is a categorical rating system between 1 and 5, which corresponds to the sustained wind speed of hurricanes (Table 32). This scale serves as an estimate of potential property damage during hurricanes. Hurricanes reaching Category 3 and higher are considered major hurricanes because of their potential for significant loss of life and property damage. The Saffir-Simpson Hurricane Wind Scale serves as a good measure for sustained wind speed; however, this scale does not account for the compounding impacts (i.e. inundation and erosion).

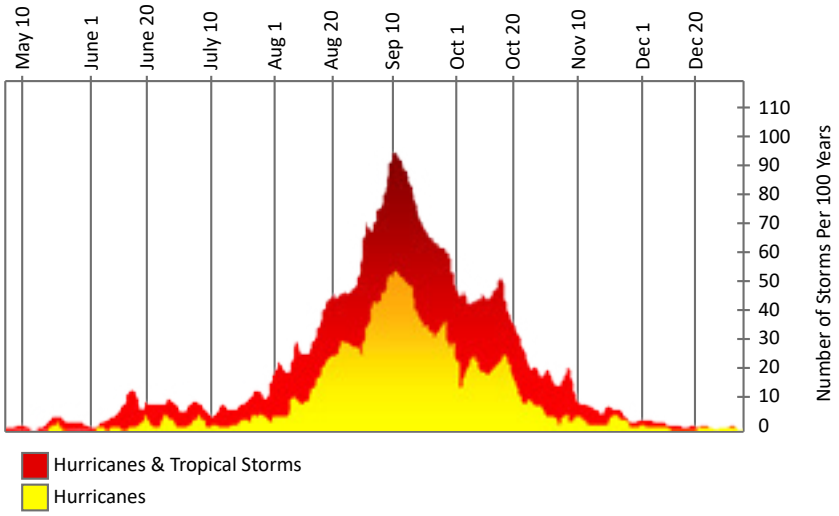

Figure 39: Peak Hurricane Season in the Atlantic Basin
Data Source: https://www.nhc.noaa.gov/climo/

1 https://www.weather.gov/btv/wwa_reference

The Atlantic Ocean hurricane season runs from approximately June 1 through November 30, with the majority of hurricane activity occurring between mid-August through October[2] (Figure 39).

Table 32: Saffir-Simpson Hurricane Wind Scale				
Tropical Depression		≤38 mph, ≤33 knots, ≤62 km/h	**Tropical Storm**	39–73 mph, 34–63 knots, 63–118 km/h
Category	**Wind Speed**	**Types of Damages Due to Hurricane Winds**		
1	74-95 mph 64-82 kt 119-153 km/h	Very dangerous winds will produce some damage: Well-constructed frame homes could have damage to roof, shingles, vinyl siding, and gutters. Large branches of trees will snap, and shallowly rooted trees may be toppled. Extensive damage to power lines and poles likely will result in power outages that could last a few to several days.		
2	96-110 mph 83-95 kt 154-177 km/h	Extremely dangerous winds will cause extensive damage: Well-constructed frame homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks.		
3 (Major)	111-129 mph 96-112 kt 178-208 km/h	Devastating damage will occur: Well-built frame homes may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes.		
4 (Major)	130-156 mph 113-136 kt 209-251 km/h	Catastrophic damage will occur: Well-built framed homes can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months.		
5 (Major)	≥ 157 mph ≥ 137 kt ≥ 252 km/h	Catastrophic damage will occur: A high percentage of framed homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Most of the area will be uninhabitable for weeks or months.		

Source: https://www.nhc.noaa.gov/aboutsshws.php

Thunderstorm:

Severe thunderstorms are capable of producing high winds (including downdrafts), large hail, lightning, flooding, rains, and tornadoes. Thunderstorm winds are generally short in duration, involving straight-line winds and/or gusts in excess of 50 mph and tend to affect areas of Vermont with significant tree stands as well as areas with exposed property and infrastructure and aboveground utilities. Winds can cause power outages, transportation and economic disruptions and significant property damage, and pose a high risk of injuries and loss of life.

Thunderstorms can produce downburst winds that affect the land immediately beneath a storm. These downburst winds are called mircrobursts and macrobrusts, which move outward from the base of a thunderstorm and can reach speeds in excess of 80 mph. Microbursts (the smaller of the two in terms of area affected) pose an extreme threat to aircraft. The downward wind can exceed the lift component of an aircraft, making it impossible to maintain altitude, which for low flying aircraft (especially during takeoff and landing) is extremely dangerous.

Thunderstorms can range in size and type. An ordinary cell thunderstorm consists of one cell with an updraft and downdraft and produce strong winds, rain, lightning, and even hail. Multicell cluster thunderstorms consist of several ordinary cell thunderstorms in the vicinity of each other. Multicell cluster thunderstorms are extremely prone to causing flash flooding. Squall line thunderstorms move in a line or front that can exceed 100 miles in length, with the strongest rains and winds at the front of the storm. Supercell thunderstorms are the largest, longest lasting, and most devastating thunderstorms. Nearly all tornadoes are formed from supercell thunderstorms. Lightning, hail, flash flooding, and tornadoes are all associated with this type of thunderstorm (see: Hail and Inundation Flooding & Fluvial Erosion).

2 https://www.nhc.noaa.gov/climo/

In Vermont, high winds are most often seen accompanying severe thunderstorms. In fact, straight-line winds are often responsible for most of the wind damage associated with a thunderstorm. These winds are frequently confused with tornadoes because of similar damage and wind speeds; however, they are not rotating like the winds of a tornado.

Thunderstorms and associated hazards can occur anywhere in Vermont at any time of the year; however, spring and summer are the most common times for severe thunderstorms.

Tornado:

A tornado is a violently rotating column of air extending from a thunderstorm to the ground. The most violent tornadoes are capable of tremendous destruction with wind speeds capable of reaching in excess of 250 mph. Damage paths can be in excess of a mile wide and 50 miles long. The Enhanced Fujita Scale is a categorical rating system between EF0 and EF5 for wind speed during a tornado (Table 33).

Since 1950, Vermont has experienced 45 tornadoes, 14 of which were magnitude F2 (significant) and 16 magnitude F1 (moderate) on the Fujita Scale. F2 tornadoes have maximum wind speeds of 113 to 157 mph, while F1 tornadoes range from 73 to 112 mph. Damage from tornadoes has ranged from a few downed trees to seven injuries during a 1970 tornado in Franklin County. These injuries occurred when a waterspout – a tornado that originates over water instead of land – moved from Lake Champlain to the southern part of Swanton, where it struck a cabin. Property damage has totaled over $8.4 million overall in the State of Vermont due to tornado damage. There have been no deaths as a result of a tornado in Vermont since 1950.

Tornadoes typically occur in Vermont between March and August; however, tornadoes can strike at any time of the year if the essential conditions are present[3].

Table 33: Enhanced Fujita Scale

Scale	Wind Speed		Types of Damages Due to Hurricane Winds
	mph	km/h	
EF0	65-85	105-137	*Minor or no damage.* Peels surface off some roofs; some damage to gutters or siding; branches broken off trees; shallow-rooted trees pushed over. Confirmed tornadoes with no reported damage (i.e., those that remain in open fields) are always rated EF0.
EF1	86-110	138-177	*Moderate damage.* Roofs severely stripped; mobile homes overturned or badly damaged; loss of exterior doors; windows and other glass broken.
EF2	111-135	178-217	*Considerable damage.* Roofs torn off well-constructed houses; foundations of frame homes shifted; mobile homes completely destroyed; large trees snapped or uprooted; light-object missiles generated; cars lifted off ground.
EF3	136-165	218-266	*Severe damage.* Entire stories of well-constructed houses destroyed; severe damage to large buildings such as shopping malls; trains overturned; trees debarked; heavy cars lifted off the ground and thrown; structures with weak foundations are badly damaged.
EF4	166-200	267-322	*Devastating damage.* Well-constructed and whole frame houses completely leveled; cars and other large objects thrown and small missiles generated.
EF5	>200	>322	*Extreme damage.* Strong-framed, well-built houses leveled off foundations are swept away; steel-reinforced concrete structures are critically damaged; tall buildings collapse or have severe structural deformations; some cars, trucks, and train cars can be thrown approximately 1 mile (1.6 km).

Source: http://www.spc.noaa.gov/efscale/ef-scale.html

3 National Weather Service, http:/www.nws.noaa.gov

Wind History

- **Tornado, May 31, 1998:** Bennington County was hit with an EF2 tornado that damaged homes and property in North Bennington. The tornado originated near Round Lake, New York, and moved rapidly eastward into Vermont, producing damage in North Bennington before dissipating in Shaftsbury. Funnel clouds were also reported that day in the Brattleboro area, but no tornadoes were confirmed to have touched down. Strong straight-line winds also damaged areas of Bennington and Windham Counties. Estimated $630,000 in property damages from this event.
- **Tropical Storm Floyd, September 16, 1999 (DR-1307):** Strong winds reaching 51 mph combined with saturated soils from heavy rain resulted in trees and power lines being blown down, causing power outages. A death occurred when a tree fell on a mobile camper in Randolph. $675,000 in estimated damages from the wind.
- **Tornado, June 5, 2002 (DR-1428):** Thunderstorms spawned two tornadoes, one in Woodford Hollow in Bennington County (EF1) and the other one near Wilmington in Windham County (EF2). The first touchdown produced a swath 150 yards wide and a path length of one-half mile. Many trees as large as a foot in diameter were either knocked over or ripped apart. Trees also fell on three automobiles. The second tornado, four miles Northeast of Wilmington, was even stronger despite a narrower swath of 50 yards.
- **Wind Storm, April 15, 2007 (DR-1698):** High winds during this April storm resulted in many trees down and damage to some private homes and public infrastructure, primarily in southern Vermont. $4.8 million in estimated damages from the wind.
- **Tornado, July 18, 2008 (DR-1784):** A tornado was reported in Bakersfield (EF1), causing localized damages. A tornado with winds reaching 100 mph ripped an apartment's roof off, snapped large trees, and destroyed a barn in the small town of Washington in May 2009. Estimated $150,000 in damages.
- **Wind Storm, December 1, 2010 (DR-1951):** Wind across the higher peaks of the Green Mountains caused strong to damaging down slope winds in excess of hurricane force to the western slope communities and wind gusts approaching 55 mph into the Champlain Valley. Much of this damage was in the form of downed limbs, branches, trees, playground sets and some isolated structural damage in the form of blown off roof shingles. Over 35,000 utility customers lost power with an estimated $3.35 million damages.
- **Tropical Storm Irene, August 28, 2011 (DR-4022):** While the vast majority of the impact from Tropical Storm Irene was due to flooding, damaging north winds of 35 to 45 mph sustained with gusts in excess of 60 mph buffeted Grand Isle county and Lake Champlain. Estimated wave heights of 4-6' and possibly higher damaged boats, moorings and knocked down or uprooted numerous trees with thousands of customers without power. An estimated $1.25 million in property damages is attributed to wind.

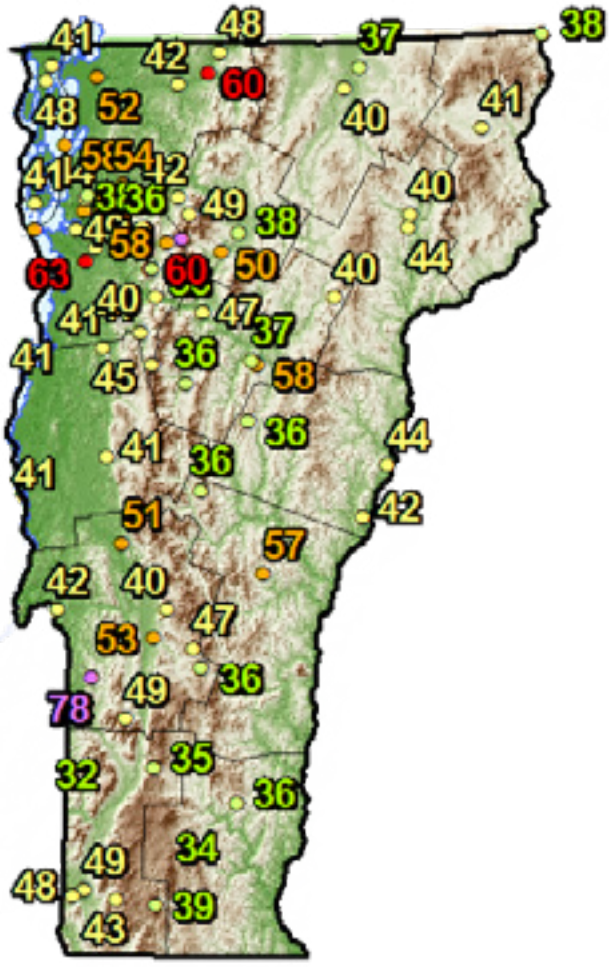

Figure 40: North Country Maximum Wind Gusts, Monday, October 30, 2017 (DR-4356)
Source: NOAA

- **Tornado, May 29, 2012 (DR-4066):** Severe storms rolled through the Northeast portion of the State. The tornado, rated as an EF0 by NOAA, had wind speeds that peaked at 70 mph, tearing 45 trees out of the ground and pelting area house with marble-sized hail. Estimated $10,000 in property damage.
- **Hurricane Sandy, October 29, 2012:** Hurricane Sandy came to the Northeast and did not significantly affect Vermont. Nevertheless, Vermont did experience high winds from the storm, especially in the southern part of the State. All of Vermont's 14 counties experienced electric utility impacts, and approximately 64,600 customers lost power. All customers had their power restored in approximately 56 hours. Estimated damages were under $1 million.
- **Wind Storm, October 30, 2017 (DR-4356):** Numerous tree damage and power outages with wind gusts of 40 to 50 mph, reaching 60 mph in some locations. $2.25 million in property damages is estimated from this event. Maximum wind gusts from this event are mapped in Figure 40.

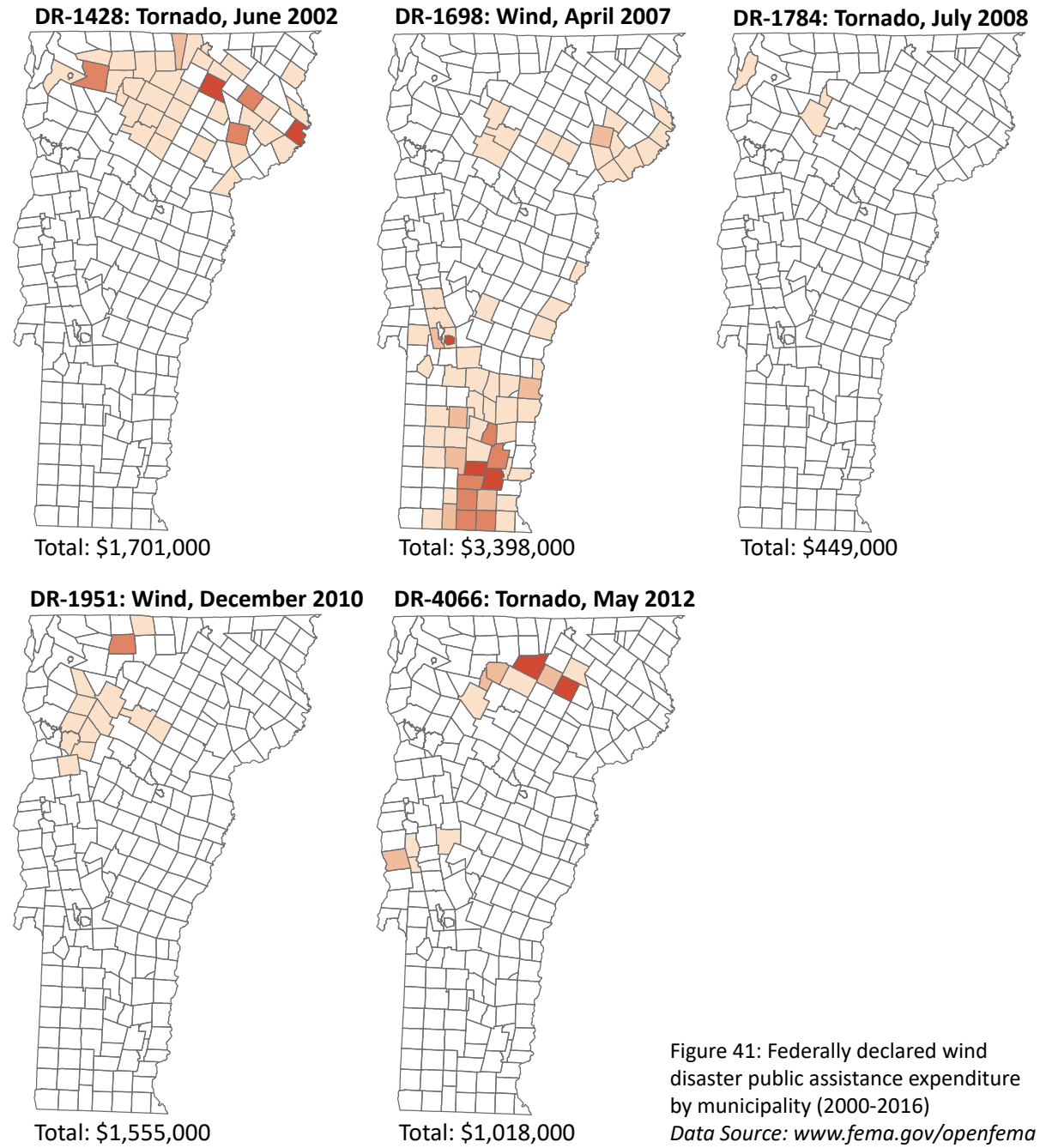

Figure 41: Federally declared wind disaster public assistance expenditure by municipality (2000-2016)
Data Source: www.fema.gov/openfema

Wind Trends & Vulnerability

Overall, wind events are considered by the Steering Committee to be Likely in Vermont. Compared to other hazard impacts, the risk due to wind events is moderate. Wind, which typically flows from west to east across Vermont, is most significant on mountain peaks, where wind speeds are highest. The most significant concern from a wind event is the impact to infrastructure, predominately utilities. High winds pose a serious concern for all electric and telecommunication utilities in Vermont due to the customer outages and damage to infrastructure they may cause. Power outages can have a significant impact on Vermonters, especially if they occur in the winter. Figure 42 shows the electric utility service territory across the State.

According to the 2014 National Climate Assessment, though there is an observable increase in severity of storms, changes in the frequency or severity of tornadoes and wind events are still uncertain but are being extensively studied[4].

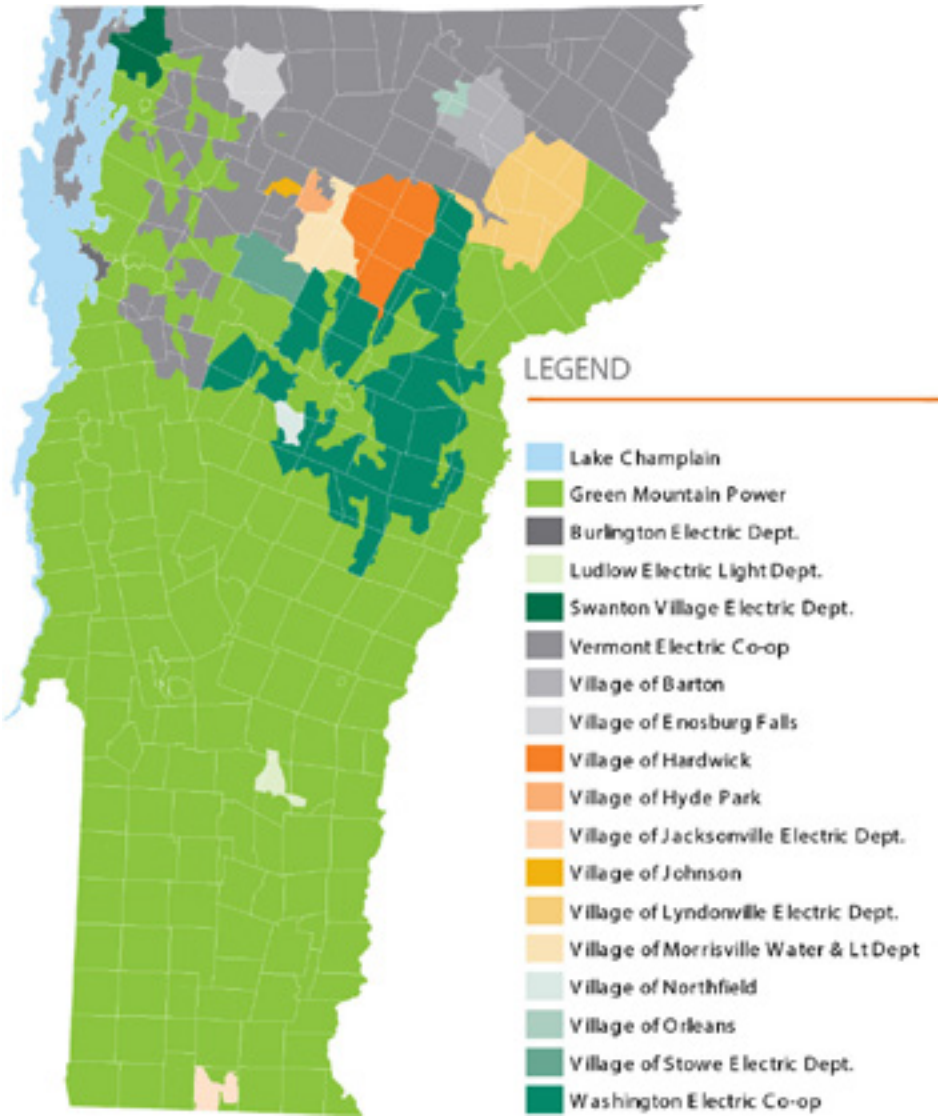

Figure 42: Electric Utility Service territory map from Vermont Public Utility Commission
Source: http://puc.vermont.gov/document/electric-service-territory-map

Wind Mitigation

Several actions within this Plan address wind events (see: Mitigation Strategy), such as the strategy on resilient design and construction standards, including actions around developing sample building standards and educational resources for resilient design and construction.

This Plan also includes a strategy to identify and protect vulnerable structures and critical infrastructure, with an action to provide technical assistance to utilities in long-range planning for transmission and distribution line upgrades and relocation to improve resilience. Additionally, this strategy includes an action to adapt the VTrans Methods and Tools for Resilience project (2018 SHMP subgrant) for use in mapping utilities and identifying vulnerabilities, which should not be a significant lift, given that the majority of utility lines in Vermont run along roadways.

4 https://nca2014.globalchange.gov/report/our-changing-climate/changes-storms

Though several towns in the State are considering burying of power lines for long-term mitigation against both wind and ice events, a statewide approach to power line burying is not being considered at this time due to being cost prohibitive.