Vermont Climate and Health Profile Report

Building Resilience against Climate Change in Vermont

September 2016

DEPARTMENT OF HEALTH

Division of Environmental Health

healthvermont.gov

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Mosquito (*Culex pipiens*): CDC photo gallery

Tropical Storm Irene damage on Vermont Route 107: Vermont Agency of Natural Resources

Lake Champlain (Sunset): Nagaraju.ramanna, available at:
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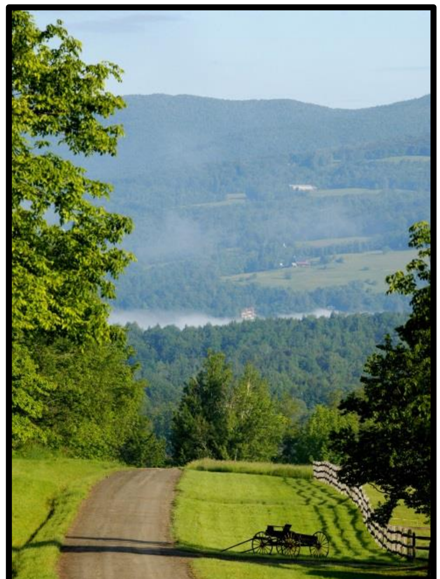


Our climate is changing and will continue to change for the foreseeable future. In response to this reality, the Vermont Department of Health, supported by a grant from the Centers for Disease Control and Prevention (CDC), has initiated a process to identify the most pressing health impacts of our changing climate and to develop public health adaptation strategies. This process follows the CDC's *Building Resilience against Climate Effects* (BRACE) framework. The BRACE framework is comprised of five steps:

1) Forecasting climate impacts and assessing vulnerabilities;
2) Projecting the disease burden;
3) Assessing public health interventions;
4) Developing and implementing a climate and health adaptation plan;
5) Evaluating the impact of the process and improving the quality of its activities.

This Climate and Health Profile Report is an important component of the first BRACE step. In addition to summarizing trends in Vermont's climate over the last century, this report presents projections of our changing climate up to the end of this century. Without a sharp reduction in greenhouse gas emissions, these projections indicate that Vermont's climate will change substantially over the coming decades. By the end of the century[1]:

1) average annual temperatures will be at least 4°F higher, and may reach up to 7°F higher;
2) the number of dangerously hot days could increase from about 5 per year to more than 30 per year;
3) the potential period of mosquito and tick activity could lengthen by about 40 days; and

[1] The Health Department partnered with State Climatologist Lesley-Ann Dupigny-Giroux and post-doctoral researcher Evan Oswald at the University of Vermont to provide Vermont-specific projections of key climate indicators. See chapter 2 for further details.

4) heavy rainfall events will become more frequent. For instance, the biggest rainstorm in an average 8-year period will instead occur about once every 3 years.

Based on a review of existing climate and health literature, the report identifies exposures of public health concern that may be exacerbated or initiated by the changing climate. It evaluates the risk of each of these exposures in the context of Vermont-specific climate projections and Vermont's particular vulnerabilities. This evaluation process identified six priority health risks that will be assessed in greater detail by the Health Department's Climate Change Adaptation Program. The six areas are:

1) **Extreme heat events:** The Health Department has identified an increase in mortality, as well as heat-related emergency department visits, on days when temperatures exceed 87°F. By the end of the century, Vermont is projected to experience close to seven times more of these high-risk days than it does now. Vermont's aging population and lack of heat-related infrastructure adaptations, such as air conditioning, are further risk factors;

2) **Air quality impacts:** Warming temperatures combined with higher atmospheric carbon dioxide concentrations are likely to result in greater allergenic pollen production over a greater portion of the year. This may worsen allergic symptoms and exacerbate asthma symptoms. In addition, warming temperatures may result in higher ground-level ozone ambient air concentrations, which in turn can lead to exacerbation of asthma symptoms and other air-quality related health problems. However, ground-level ozone concentrations are also dependent on emissions of nitrogen and sulfur oxides through combustion, which may decrease as Vermont's fossil fuel usage decreases.

3) **Extreme weather events:** Vermont already suffers from annual flooding. The projected increase in the frequency of heavy precipitation events is likely to exacerbate this chronic problem. While it is more difficult to project the actual occurrence of very rare large-scale catastrophic events of the magnitude of Tropical Storm Irene, the pattern of increase in weather extremes suggests that the risk of such events will rise as well. A consistent increase in heavy precipitation will likely worsen erosion and thus increase our vulnerability to catastrophic events when they do occur. Road closings and damage to transportation infrastructure may impede access to health care services. Also, more frequent heavy precipitation has the potential to create hazardous conditions at swimming holes and may result in increased drownings.

4) **Mosquito and tick-borne diseases:** The exact nature of the relationship between climate and the incidence of vector-borne diseases such as Lyme disease, West Nile virus and Eastern equine encephalitis (EEE) is complex and still poorly understood. However, projections show a future climate in which mosquitos and ticks can become active earlier in the spring and can remain active into the late fall, extending their period of activity by about 40 days by the end of the century. This is particularly worrisome as Vermont already has one of the highest rates of Lyme disease in the United States. Over the long term, the warmer climate may also permit the spread of new mosquito and tick disease vectors into our state.

5) **Foodborne and waterborne pathogens:** Warmer temperatures and more frequent downpours are likely to create a more favorable environment for the proliferation of foodborne and

waterborne pathogens. Furthermore, many Vermonters rely on small water systems and private wells for their drinking water and may thus be at greater risk for waterborne disease.

6) **Cyanobacterial blooms:** Cyanobacterial blooms are complex natural phenomena and predicting their response to a changing climate is difficult. However, intense precipitation poses the risk of increasing nutrient inputs, which, combined with warmer temperatures, may result in more favorable conditions for cyanobacterial blooms in Vermont's lakes.

Some general vulnerabilities that contribute to the selection of the above focus areas include Vermont's:

1) Aging population;
2) Higher prevalence of asthma;
3) Extensive commercial and residential development in flood-prone and erosion-prone areas;
4) Widespread participation and economic interest in outdoor recreation, including swimming, fishing, hiking, hunting, gardening;
5) Widespread participation and economic interest in farming; and
6) Substantial reliance on small water systems and private wells.

The report concludes with a discussion of how the focus areas will be addressed in future steps of the BRACE framework, including planned epidemiological analyses and key partnerships and collaborations that will lead to the development and implementation of adaptation strategies.

1. Introduction

1.1 Rationale

Vermont's seasons and weather patterns are ingrained into our way of life. Over the centuries, we have attempted to adapt our homes, infrastructure and even health services delivery to the bitter cold snaps, blizzards, and summer downpours that the State experiences. However, beneath the regular seasonal cycles and the shorter-term fits and bursts of weather, trends of longer-term change have emerged. For example, temperatures have been warming by about 0.5°F per decade since 1960 (Betts 2011). The excess heat trapped in our atmosphere affects other aspects of our climate, leading to increased rainfall and accentuating variability in heavy rainfall events (Betts 2011).

Recognizing that global climate change is primarily driven by greenhouse gas emissions, the State of Vermont has taken aggressive steps to curb the State's contribution to this global problem. In 2005, the State Legislature codified into law plans to reduce greenhouse gas emissions by 25% by 2012, 50% by 2028 and, if practicable, 70% by 2050 (Vermont State Legislature, 2005). However, while decreases in greenhouse gas emissions are needed to reduce the magnitude of future climate change, even deep global reductions would not prevent changes to the climate that have already been set in motion. The State is complementing its efforts to reduce emissions with the development of climate adaptation strategies by its agencies and departments. The Vermont Department of Health contributed to this effort by drafting the *Vermont Climate Change Health Effects Adaptation* white paper in 2011. The paper identified some potential health impacts of climate change in Vermont and inventoried existing public health resources that could be used to manage them. In September 2012, the Health Department was awarded a four-year grant from the Centers for Disease Control and Prevention (CDC) to address the anticipated health impacts of climate change in a more systematic way. To do so, the Health Department has adopted the *Building Resilience against Climate Effects* (BRACE) framework developed by the CDC. The BRACE process consists of five steps:

1) Forecasting climate impacts and assessing vulnerabilities: identifying the scope of likely climate impacts, the potential health outcomes associated with those climatic changes and the populations and locations most vulnerable to them;
2) Projecting the disease burden: estimating the anticipated additional burden of health outcomes due to climate change so as to support prioritization and decision making;
3) Assessing public health interventions: identifying the most suitable health interventions for the health impacts of greatest concern;

4) Developing and implementing a climate and health adaptation plan: developing and implementing a health adaptation plan for climate change that addresses health impacts, gaps in critical public health functions and services, and a plan for enhancing adaptive capacity;
5) Evaluating the impact and improving the quality of climate and health activities: evaluating the processes used, determining the value of utilizing the BRACE framework and the value of climate and health activities undertaken and incorporating refined inputs such as updated data or new information.

What is the Climate and Health Profile Report?

This Climate and Health Profile Report (CHPR) is part of the first BRACE step. The CHPR:

1) Summarizes climate trends and future projections for Vermont;
2) Synthesizes five major reviews of the health impacts of climate change and describes exposures of potential public health concern in Vermont;
3) Based on targeted literature reviews, describes how each exposure is related to the changing climate;
4) Describes the populations most vulnerable to the identified exposures;
5) Evaluates the public health threat posed by each exposure in the context of Vermont-specific climate projections and Vermont's particular vulnerabilities;
6) Based on this evaluation, identifies six exposures to undergo further analysis using the remaining steps of the BRACE framework;

The six selected focus areas will undergo a more thorough quantitative assessment. Epidemiological analyses will help identify vulnerable groups more precisely and will attempt to project future disease burdens. This deepened understanding of vulnerable groups and disease burdens will inform the development of adaptation strategies in collaboration with community partners.

A key component of the first BRACE step is the use of climate projections. While historic climate records clearly show evidence of existing trends, they do not quantify future change. Computer-based global climate projections attempt to account for incremental changes in climate and emissions over time. The projections used for this document are made from the present to the end of this century.

What the Climate and Health Profile Report is not

- The CHPR is not intended to inform greenhouse gas emissions reduction efforts. The urgent need for such reductions is already widely recognized by international organizations, the Federal Government and the State of Vermont. Public health adaptation strategies are developed *in addition to* emissions reduction plans and not instead of them.
- The CHPR is not a comprehensive report on all climate impacts and on adaptations in all sectors. The report views climate change solely through the lens of public health impacts. It does not comment on climate-driven economic or cultural disruptions *except* as they relate to human health.
- The CHPR is not a global or even regional analysis. The report concerns itself exclusively with Vermont. Climate-change driven health impacts vary substantially by geography. The impacts identified in Vermont are not necessarily transferable to neighboring states, let alone to other continents. In some regions, climate-driven health impacts may be less severe than in Vermont,

while in other regions they may be much worse. The responsibilities that Vermonters may have towards regions affected more severely by climate change is beyond the scope of this report.

1.2 History of engagement with Climate and Health

Between April 2011 and February 2013, Vermont State agencies and departments drafted a series of eight sector-specific climate change adaptation white papers. The sectors addressed by these papers included agriculture, water resources, recreation, forestry, fish and wildlife, transportation, public safety and public health. The sector-specific papers were supplemented by a ninth white paper entitled *Climate Change in Vermont* which generally describes climate trends and discusses regional projections.

Based on a literature review, the Health Department's white paper *Vermont Climate Change Health Effects Adaptation* described the potential health impacts of climate change in Vermont as well as likely vulnerable groups. Additionally, the paper described possible public health adaptation strategies and inventoried existing public health resources that could be engaged in their implementation. The assessment did not however attempt to quantify the burden of climate-related adverse health outcomes as neither Vermont –specific climate projections nor Vermont epidemiological studies linking health outcomes to climate were available at the time of its writing.

In addition to this preliminary work on climate change and health adaptation, the Health Department has had to respond to extreme weather-related health events. For instance, Tropical Storm Irene in August 2011 triggered the activation of the Health Operations Center as the Health Department sought to address the public health implications of widespread flooding, disruption of transportation networks and power outages. Flooding of the Waterbury complex, which houses the State's Emergency Operations Center, highlighted the State Government's own vulnerability in the face of extreme weather events.

Over the years, the Health Department has also distributed numerous press releases in advance of episodes of extreme heat, or to warn of strong dangerous swimming conditions and sewage overflow in recreational waters following heavy rainfall. Furthermore, the Health Department deals with a range of seasonal health issues that are at least in part mediated by climate. For instance, the Health Department supports a cyanobacterial (blue-green algae) monitoring initiative that alerts recreational water users of the location of algal blooms. Additionally, a major Health Department priority has been its response to the emergence or reemergence of Lyme disease, West Nile Virus and most recently Eastern Equine Encephalitis virus. These responses have necessitated the implementation of surveillance systems, mosquito testing programs, education campaigns and vector control measures. Outdoor air quality is regulated and monitored by the Department of Environmental Conservation in turn is responsible monitoring air quality, which is also mediated by climate.

1.3 Geographic Scope

The potential health impacts of climate change in Vermont are assessed over the entirety of the state. Vermont is primarily a rural state with low population density. The 2010 U.S. census found that 61% of Vermont's population lives in rural areas, making it the most rural state in the nation after Maine (U.S. Census Bureau 2010). Vermont's rural character and its location on the northern boundary of the United States highlight the need for local analyses of climate change impacts, since exposures, existing adaptive capacities and vulnerabilities differ from more southern or urbanized areas.

2. Vermont's Changing Climate

The Intergovernmental Panel on Climate Change's (IPCC) most recent (5th) assessment made clear that "warming of the climate is unequivocal, as is evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level rise" (IPCC 2013). Furthermore, it concluded that the release of greenhouse gases by human activity is extremely likely to be the dominant cause of these changes (IPCC 2014). In fact, the analysis of ancient ice indicates that greenhouse gas concentrations are now substantially higher than they have ever been over the last 800,000 years (IPCC 2013). Figure 1 illustrates the dramatic increase in atmospheric carbon dioxide concentration over the last century, with an accompanying increase in global temperatures. This section explores how the changing global climate impacts Vermont. Section 2.1 looks at climate trends that the state has already experienced. Section 2.2 presents modeled projections of future climate.

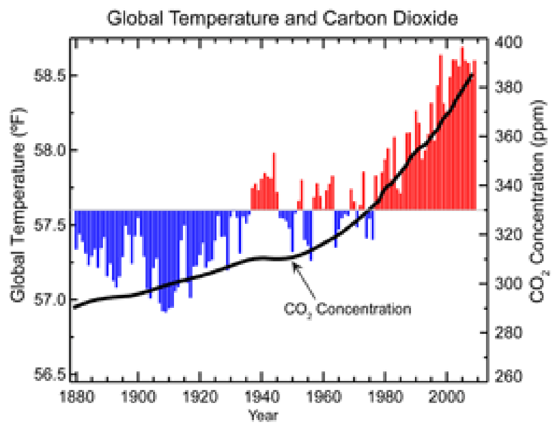


Figure 1: Global annual average temperature measured over land and oceans. Red bars indicate temperatures above and blue bars indicate temperatures below the 1901-2000 average temperature. The black line shows atmospheric carbon dioxide concentration in parts per million. (NOAA 2013)

2.1 Climate Baseline and Trends

Much of the trend data presented here is drawn from the National Climate Assessment for the Northeast Region, by Kunkel et al (2013). The Northeast region as defined in that assessment consists of Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Delaware, Maryland, and West Virginia, as well as Washington DC. Regional assessments are carried-out on a regular basis for the United States Global Change Research Program, as mandated by the Global Change Research Act. Additional information is drawn from Alan Betts' White Paper *Climate Change in Vermont*, as well as several other climate resources.

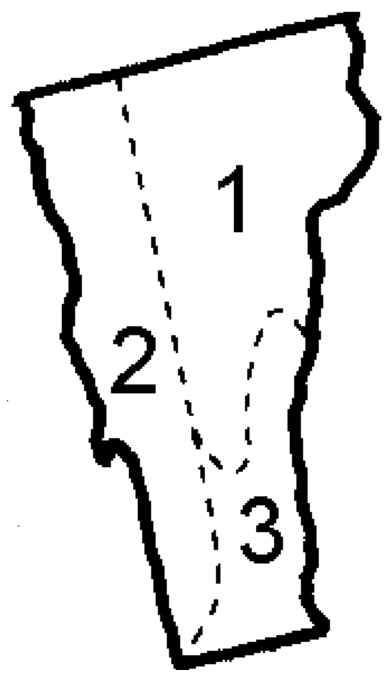


Figure 2: Vermont climatological divisions. 1) Northeastern 2) Western 3) Southeastern. (NOAA 2013)

The National Oceanic and Atmospheric Administration (NOAA) describes Vermont's climate as characterized by the following:

1) highly variable weather over short time-scales;
2) large ranges of temperature, both daily and annually;
3) great differences between the same seasons in different years;
4) even distribution of precipitation; and
5) high level of geographic heterogeneity of climatological averages. (NOAA 2013).

Regional climate is heavily influenced by varying elevations (most of Vermont's surface ranges from 500 to 2,000 feet in elevation), types of terrain and distances from the Atlantic Ocean and Lake Champlain.

NOAA divides the state into three climatological divisions: (1) Northeastern, (2) Western and (3) Southeastern (Figure 2).

The Northeastern division covers much of the Green Mountains as well as the undulating terrain of the Northeast Kingdom. It is the coolest of the divisions: July and January averages are of 66 ºF and 15 ºF respectively (30-year average calculated in 2002). The Western division lies in the Champlain Valley and its climate is somewhat moderated by Lake Champlain: July and January average temperatures are of 69 ºF and 18 ºF respectively. The Southeastern area is influenced by the Atlantic, with a July average of 68 ºF and a January average of 19 ºF (NOAA 2013). While the climatological divisions are useful tools in describing the State's climate, they do not represent areas of homogenous climate and do not capture all local climate variability, including frost hollows or snow summits and snow shadows.

Climate versus Weather

The National Oceanic and Atmospheric Administration (NOAA) defines climate as:

"*The average of weather over at least a 30-year period.*" (NOAA 2004)

Weather is variable, particularly in Vermont. Thus a single decade, let alone a single day, of weather data cannot be used to describe climate change. Rather multi-decadal datasets and multi-decadal projections need to be used.

(Photo: National Weather Service gallery)

2.1.1 Temperature Trends

Over the last century, temperatures have warmed across the Northeast by about 0.16 °F per decade (Kunkel et al 2013). As Table 1 shows, this warming is not distributed evenly across seasons, with winter temperatures rising more than twice as much as summer temperatures (Kunkel et al. 2013).

Table 1: Seasonal warming trends in the Northeast over the last century (Kunkel et al. 2013).

Season	Temperature Increase °F/decade
Winter	0.24
Spring	0.14
Summer	0.11
Fall	0.12
Annual	0.16

The warming trend is sharper if calculated from 1960 onwards instead of from the beginning of the century. Figure 3 shows temperature trends for Vermont since 1960. Average temperatures in Vermont have risen by about 0.5°F per decade since 1960, with winter temperatures increasing by about 0.9°F/decade (±0.28) and summer temperatures by 0.4°F/decade (±0.12) (Betts 2011). In other words, winter and summer temperatures are respectively about 4.5°F and 2°F higher than they were in 1960.

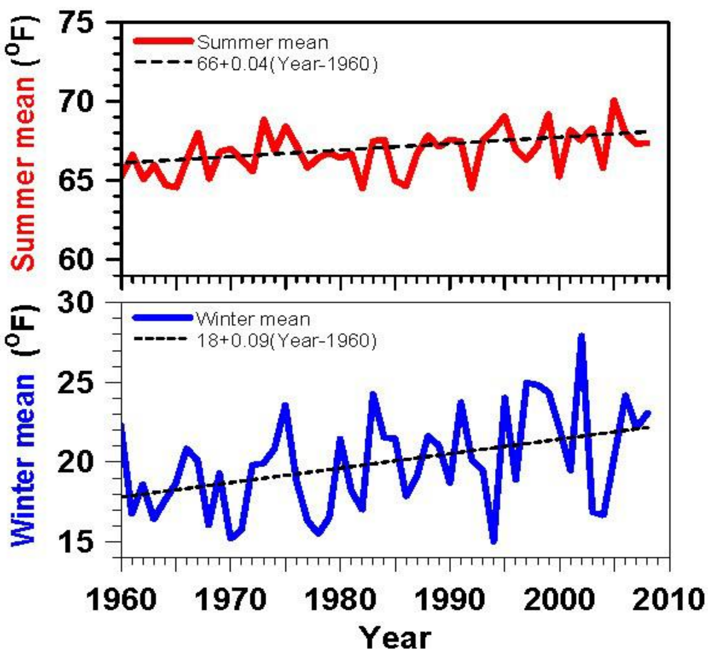


Figure 3: Trends in summer and winter temperature in Vermont (Betts 2011) Based on stations at Burlington, Cavendish, Enosburg Falls and St. Johnsbury.

2.1.2 Freeze-free and Growing Seasons

As a result of this gradual warming, Vermont's growing season has increased by about 3.7 days per decade (±1.1), and its freeze-period has decreased by 3.9 days per decade since 1960 (Betts 2011). In other words, Vermont's freeze-free and growing seasons are about two weeks longer than they were in 1960. An increase in the freeze-free season is also observable over the Northeast as a whole, calculated over a longer, 100-year period (Kunkel et al. 2013).

2.1.3 Ice-cover and Snow Depth

The period of ice cover on Vermont's lakes is decreasing. The freeze period on Stile's Pond in Waterford, Vermont, has decreased by close to one month since 1970 (Betts 2011). Between 1970 and 2013, Lake Champlain did not freeze over during the winter on 18 occasions. In contrast, it had frozen-over for all but three winters in the 1800s and all but three between 1900 and 1940 (Kunkel et al. 2013). Similarly, snow depth has been decreasing in New England, with a 16% decrease noted in southern Maine between 1926 and 2004 (Kunkel et al. 2013).

2.1.4 Extreme Heat Event Trends

There is no universally accepted definition of an extreme heat event. The National Climate Assessment (NCA) for the Northeast region defined extreme heat events as the occurrence of 4 consecutive days with temperatures above the 80th percentile across several sites in the Northeast; these events did not show a statistically significant increase over the last century (Kunkel et al. 2013).

2.1.5 Precipitation Trends

Annual precipitation has been trending upwards in the Northeast, with an increase of 0.24 inches per decade (Kunkel et al. 2013). Precipitation increases in the Northeast are not evenly distributed across seasons. Precipitation during the fall season has exhibited a particularly strong upward trend of 0.39 inches per decade above the baseline mean; trends during other seasons have not been statistically significant (Kunkel et al. 2013). Figure 4 shows trends in annual precipitation for Vermont alone, over the 1895 to 2013 period. The extensive variability of precipitation over the last century complicates trend calculations, though the last 30 years have seen large annual rainfall (LSU 2013). Seasonal precipitation graphs can be found in Appendix 1.

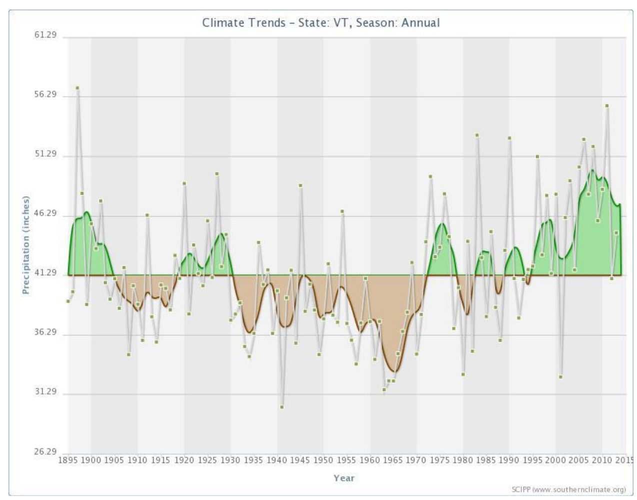


Figure 4: Annual precipitation in Vermont, 1895 to 2013. Green and brown curves indicate rolling 5-year precipitation average. The centerline represents average precipitation over the time period. Data from NOAA's Nationald Climate Data Center. (LSU 2013).

2.1.6 Extreme Precipitation Trends

Much of the increase in precipitation that the Northeast has experienced can be attributed to increases in heavy rainfall events (Groisman et al. 2004). There is no generally accepted definition of what constitutes a heavy rainfall event. Different indicators are used by different researchers. In Figure 5, heavy precipitation is defined as the top 1% of daily rainfall events recorded over the 1958 to 2007 period. The total amount of rain that falls during the top 1% of events has increased nationally and especially in the Northeast, which has seen a 67% increase (Karl et al. 2009).

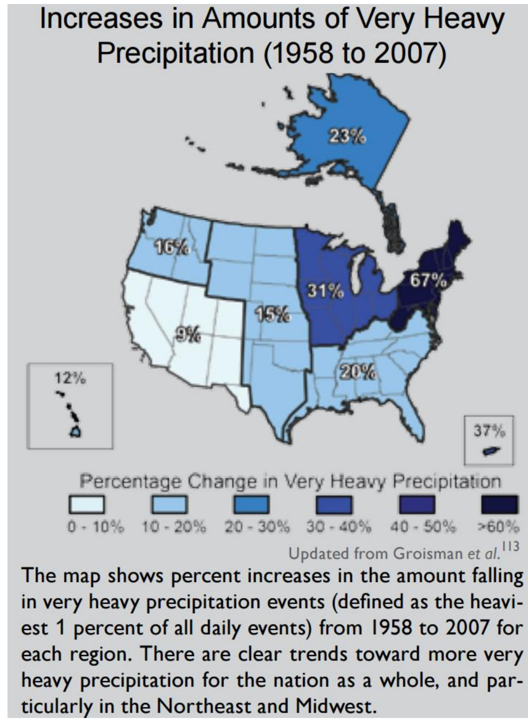


Figure 5: Increases in amount of rain falling in 99th percentile rainfalls (Karl et al. 2009)

Figure 6 shows the annual number of rainfall events in the Northeast exceeding the 95th percentile of rainfall events over the 1895 to 2011 period. While the trend appears to be increasing, the trend-line is not statistically significant, highlighting the difficulties in making statistical inferences about rare weather events.

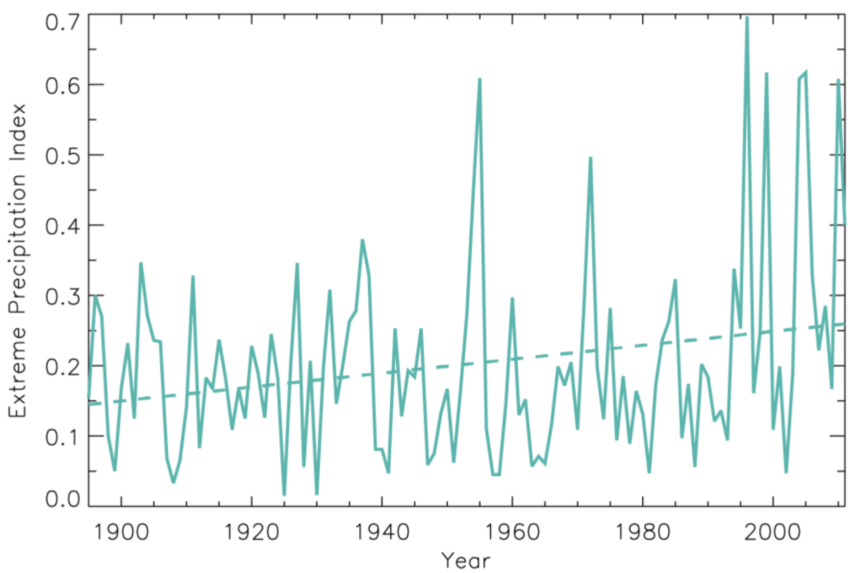


Figure 6: Annual number of events exceeding the 95th percentile, in the Northeast, averaged over 1x1 degree grid (Kunkel et al. 2013)

A pragmatic measure of change in heavy precipitation is its effect on design storms. Design storms represent the biggest storm that a piece of infrastructure must be designed to withstand within a set time period. That period is known as the “return period.” Common return periods are 2 years, 5 years, 10 years, 25 years and 100 years. The design storms currently used in Vermont and several other parts of the country were calculated by applying statistical methods to rainfall data spanning the period 1938 to 1958 (Hershfield 1961). Recalculated design storms across the country that use similar statistical methods but newer rain data can yield different design storms (DeGaetano 2009). Cornell University’s Northeast Regional Climate Center hosts a site, PrecipNet, which presents recalculated storms by county for New York and New England based on rain data updated to 2008 (PrecipNet 2013). Figure 7 compares some currently used and updated design storms for Vermont’s counties. While some parts of the Northeast have experienced substantial increases in the depth of their design storms, in Vermont changes have been fairly small and have included a mixture of increases and decreases.

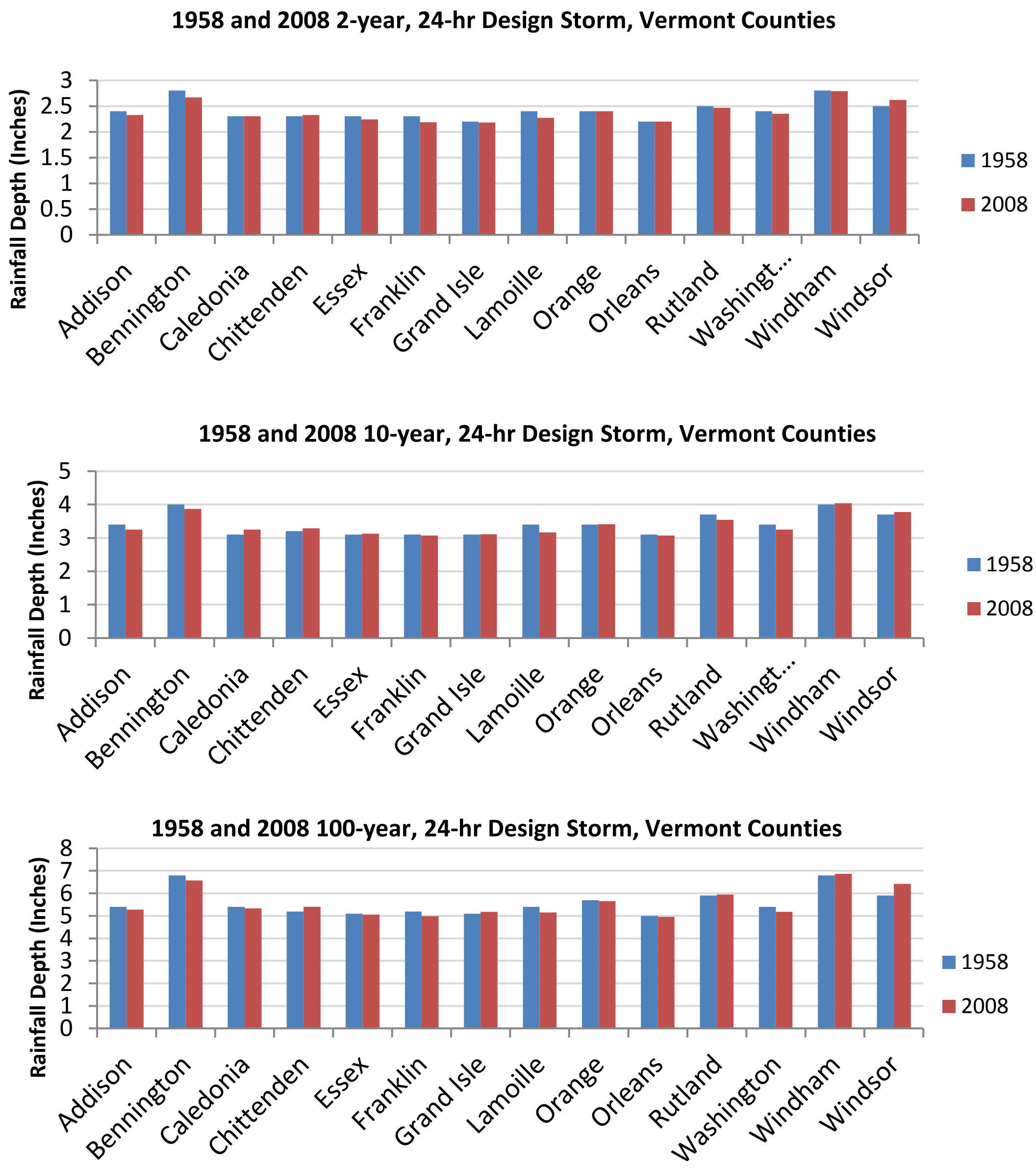


Figure 7: Current and updated 2-year, 10-year and 100-year, 24-hour design storm depths for Vermont counties. Current design storms taken from the Vermont Stormwater Manual (ANR 2004) and updated storms taken from Northeast Regional Climate Center (PrecipNet)

Storm durations of 24-hours are most commonly used for design purposes. However, shorter and longer storm durations also do not appear to show a clear increasing trend in rainfall depth in Vermont (Appendix 2). Extreme precipitation events are of paramount importance to Vermonters. In addition to the dramatic damage caused by Tropical Storm Irene in 2011, there have been 29 flood-related Major Disaster Declarations in the State since 1984 (FEMA 2016). It thus may come as a surprise to many Vermonters that the trend in extreme precipitation events is not more pronounced. Figure 6 illustrates the difficulty in drawing statistically significant trends from extreme events. The figure shows the frequency of what amounts to roughly a 5-year rainfall event. While the trend line in the figure is clearly increasing, the rare nature of the events makes it very difficult to ascertain if the trend is real, or an artifact of chance. Finding a significant trend in the occurrence of still more rare events, such as the 100-year storm, is even more difficult.

How Many 100-Year Storms Are There in 100 Years?

A 100-year return period does not in reality mean that a storm will occur every 100 years. Rather, for every 1,000 years of record, we would expect to see 10 storms of rainfall depth equal to the 100-year design storm. Or, put another way, every year in this 1,000 year period has an equal 1% chance of experiencing a 100-year event. Thus, the probability of *at least* one 100-year storm occurring over a single 100-year period is actually 64% and the probability of no 100-year storm occurring is 36%. (Photos: top: Vermont Public Radio, bottom: Vermont Agency of Natural Resources)

2.1.7 Trends in Heavy Snowfall and Ice storms

The frequency of heavy snowfall events has increased over New England over the 1901 to 2000 period (Changnon et al. 2006). The average annual number of snowfall events of depth 6 inches or more in 2 days or less is higher for the second half of the last century than the first half, as seen in Figure 8 (Changnon et al. 2006). The magnitude of this change is less than one snowstorm per year. In contrast to the increase in snowstorms, the Northeast has seen a statistically significant downward trend in the occurrence of ice storms (CCSP 2008). Ice storms appear to be decreasing nationally (CCSP 2008).

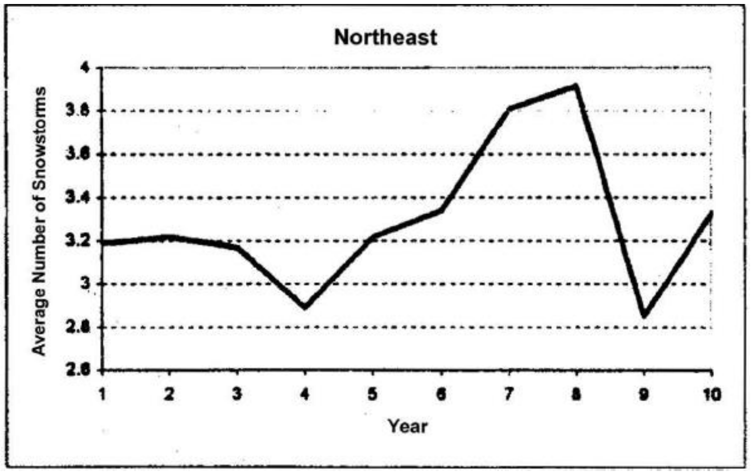


Figure 8 : Average number of snowstorms per year in New England. Snowstorms defined as 6 inches or more over 2 days or less. 1=1901-1910, 2=1911-1920...10=1991-2000 (Chagnon et al. 2006)

2.2 Introduction to Projections

Section 2.1 described climate trends in Vermont and the Northeast. However, simply extending those trends forward would not accurately describe future climate change, which depends on several dynamic factors, most notably on future greenhouse gas emissions, and is therefore not linear. Climate models must thus be used to evaluate the range of likely future climates. The Health Department partnered with State Climatologist Lesley-Ann Dupigny-Giroux and post-doctoral researcher Evan Oswald at the University of Vermont to provide Vermont-specific projections of key climate indicators. These indicators were extracted from a dataset created for the National Climate Assessment's Northeast Region section by Dr. Katherine Hayhoe. This dataset in turn is based on the output of 11 climate models known alternately as Global Climate Models or General Circulation Models (GCM). GCMs are complex simulations of our planet's climate system. The Coupled Model Intercomparison Project (CMIP) sets guidelines for climate modelers to facilitate the comparison of output from different models. Since each GCM is built somewhat differently, each produces different projections. By using the average of the forecasts of a large number of models, a more accurate result is obtained. The output of GCMs is spatially course, covering grid cells of several hundred miles. The dataset created by Dr. Hayhoe consists of this coarse GCM output that has been statistically correlated to local weather data in a process known as "downscaling." This downscaling yields projections for a higher-resolution, 1/8th degree (8 x 6 mile) grid. The 11 GCMs used were drawn from the CMIP3 round of simulations, which was compiled between 2005 and 2006.

2.2.1 Emissions Scenarios

Estimates of future greenhouse gas emissions are a critical component of climate models. But how will these emissions change over the coming century? The Intergovernmental Panel on Climate Change (IPCC) examined possible emissions trajectories in its Special Report on Emissions Scenarios (IPCC 2000). The report describes four families of emissions scenarios, each considered to have an equal probability of occurring (IPCC 2000). The four families of scenario (A1, A2, B1, B2) are shown in Figure 9. The two scenario families used in this report are the A2 and B1. These scenarios are described below. Neither scenario assumes greenhouse gas emissions reduction efforts, such as reduction treaties, to be implemented per se, though the B1 scenario assumes a more sustainable pattern of development that does in turn result in decreased emissions.

The A2 scenario describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change is more fragmented and slower than in other storylines (IPCC 2000).

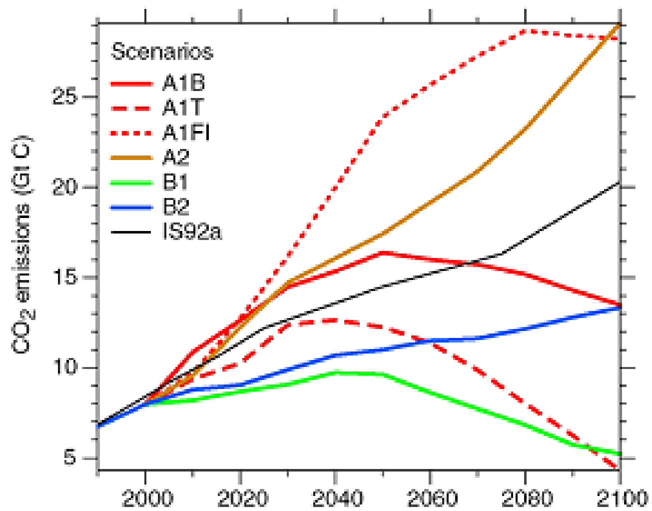


Figure 9: SRES scenarios. The graph includes the 3 sub-groups of the A1 family, as well as the IS92a scenario, which was an earlier modeling scenario and not part of the SRES. A2 and B1 are used in this report. (Graph from Nakicenovic et al. 2000)

The B1 scenario describes a convergent world with a global population that peaks in midcentury and declines thereafter, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives (IPCC 2000).

2.2.2 Time Slices

GCMs are by definition climate models and *not* weather models. As seen in section 2.1, climate is generally understood as the average weather over at least a 30-year period. Thus GCMs do not project the weather over a specific future year, but rather the average weather over a future 30-year period, known as a time slice. This report presents results for three time slices: 2021 to 2050, 2041 to 2070 and 2070 to 2099. These projections are compared to a baseline climate representing the 1981 to 2010 period. The more distant a projection is, the more uncertain it becomes. GCM projections beyond a 100-year timeframe are not included in this review.

2.3 Summary of Climate Projections

The subsections below summarize projections for key climate indicators. A total of 48 variables were projected for the two emissions scenarios and three time slices. These were calculated both as state-wide averages and as averages for each of Vermont's climate regions. Only the indicators deemed to be of greatest public health interest are presented here. These indicators are presented as state-wide averages. Complete tables of other indicators and for indicators for specific climate regions, as well as their standard deviations can be found in Appendix 3.

2.3.1 Temperature

Annual average temperatures are projected to continue to increase across Vermont. Table 2 summarizes the projected increase in average minimum and maximum daily temperatures over the year and by season, as compared to the 1981-2010 baseline. A warming of about 7°F is modeled by the end of the century under the A2 scenario, and about 4ºF under the B1 scenario. Figure 10 shows the projected seasonal increase in both minimum and maximum daily temperatures by season for the A2 scenario. Warming is most pronounced in the winter and in particular in winter minimum temperatures.

Table 2: Projected change in average maximum and minimum temperatures (°F) in Vermont compared to 1981-2010 averages (Seasons by month: Winter = DJF, Spring = MAM, Summer = JJA, Fall = SON)

Time Slice	A2 Scenario									
	Annual		Winter		Spring		Summer		Fall	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
2021-2050	2.1	2.3	1.8	2.9	2.4	2.2	2.1	2.0	2.2	2.0
2041-2070	3.7	4.2	3.5	5.7	3.7	3.7	3.8	3.7	3.7	3.7
2070-2099	6.6	7.4	5.9	9.5	6.7	6.7	6.7	6.7	6.8	6.6
Time Slice	**B1 Scenario**									
2021-2050	1.7	2.0	1.3	2.2	1.8	1.9	1.7	1.7	1.9	2.0
2041-2070	2.7	3.0	2.4	4.0	2.8	2.9	2.7	2.6	3.0	2.9
2070-2099	3.7	4.1	3.2	5.3	3.7	3.6	3.9	3.7	4.0	3.7

With the warming described above, Vermont is expected to experience a decrease in days with freezing temperatures. Table 3 summarizes the change in the dates of first and last frosts and the length of the freeze-free season. illustrates the change in the total annual number of days of freeze. This change in freeze-season may impact the period of activity of ticks and other disease vectors.

Table 3: Date of first and last frost and inrcease in freeze-free season.

Time slice	Date of First Frost		Date of Last Frost		Increase in freeze-free season length (days)	
	B1	A2	B1	A2	B1	A2
Current	28-Sep	28-Sep	16-May	16-May	-	-
2021-2050	4-Oct	5-Oct	12-May	11-May	10	12
2041-2070	5-Oct	9-Oct	10-May	7-May	13	20
2070-2099	9-Oct	19-Oct	8-May	30-Apr	19	37

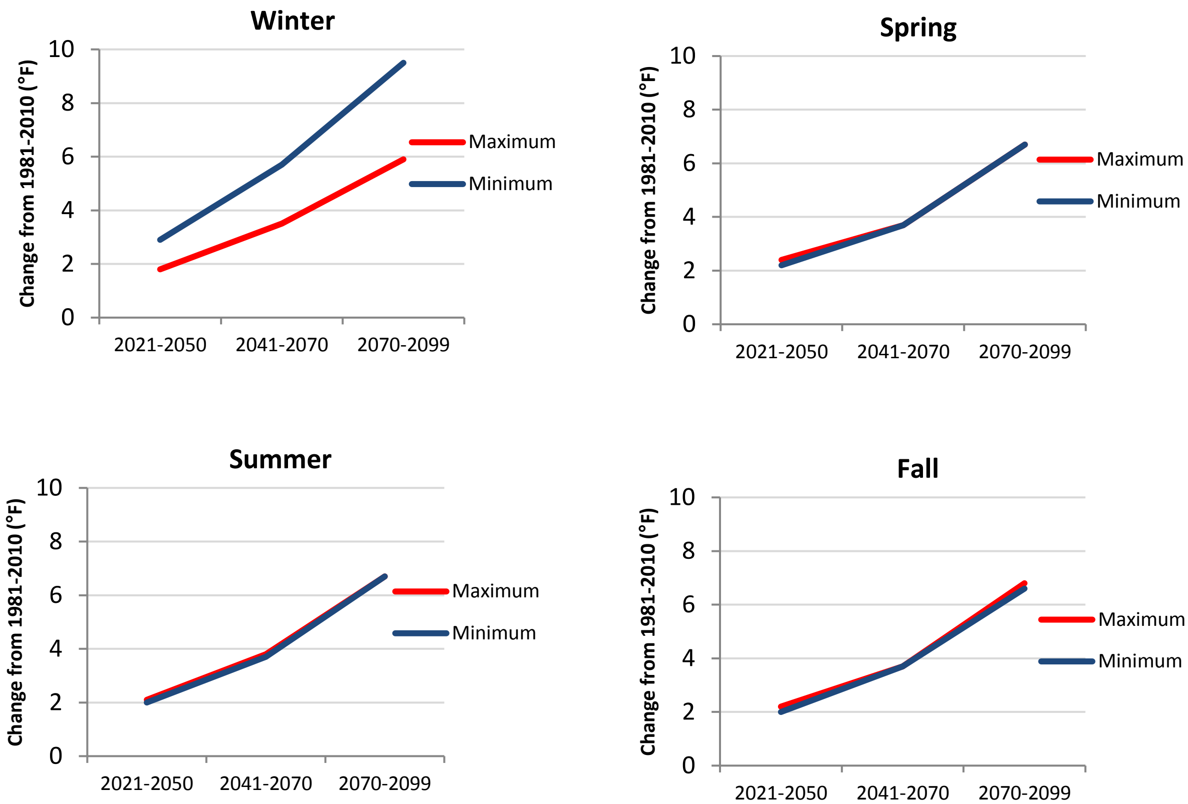


Figure 10: Increase in seasonal average minimum and maximum daily temperatures in Vermont, under the A2 scenario, as compared to the 1981-2010 baseline. Note that the increase is highest in the winter months.

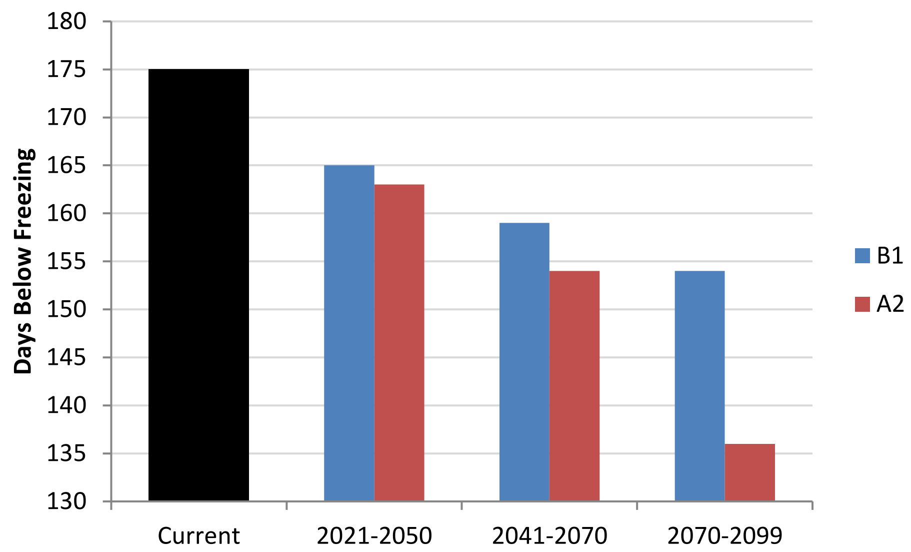


Figure 11: Current (1981-2010) and projected number of days below freezing under A2 and B1 scenarios

Preliminary research by the Northeast Regional Climate Center (NRCC) suggests that the eggs of West Nile Virus carrier *Culex* mosquitos begin to develop after March 15 on days when temperatures exceed 50°F (NRCC 2013). Furthermore, beyond 50°F, the rate of development increases with temperature (Gong et al. 2010). Emergence of adult mosquitoes occurs after the accumulation of 230 degree days of base 50°F (NRCC 2013). Thus the date of first accumulation of 230 degree days of base 50°F after March 15 can be used as an indicator of the start of the *Culex* season. Conversely, the date of first frost can be used as an indicator of the season's end (NRCC 2013). Table 4 presents an estimate of the start and end dates of the *Culex* season and the total lengthening of their period of activity.

Table 4: Projected change in mosquito season length

	B1			A2		
Time slice	**Hatch Date**	**First Frost Date**	**Season Increase (days)**	**Hatch Date**	**First Frost Date**	**Season Increase (days)**
Current	10-Jun	28-Sep	-	10-Jun	28-Sep	-
2021-2050	3-Jun	4-Oct	13	2-Jun	5-Oct	15
2041-2070	31-May	5-Oct	17	29-May	9-Oct	23
2070-2099	29-May	9-Oct	23	20-May	19-Oct	42

2.3.2 Extreme Heat

Along with projected warming temperatures, the number of very hot days is expected to increase (Kunkel et al. 2013). The Health Department's epidemiological analysis of extreme heat events has indicated a rise in heat-related illness and death on days when maximum temperatures exceed 87°F. Figure 12 summarizes the projected change in the annual occurrence of such days across Vermont. Table 5 summarizes the average date of first occurrence of temperatures exceeding 87°F and the greatest consecutive number of such days.

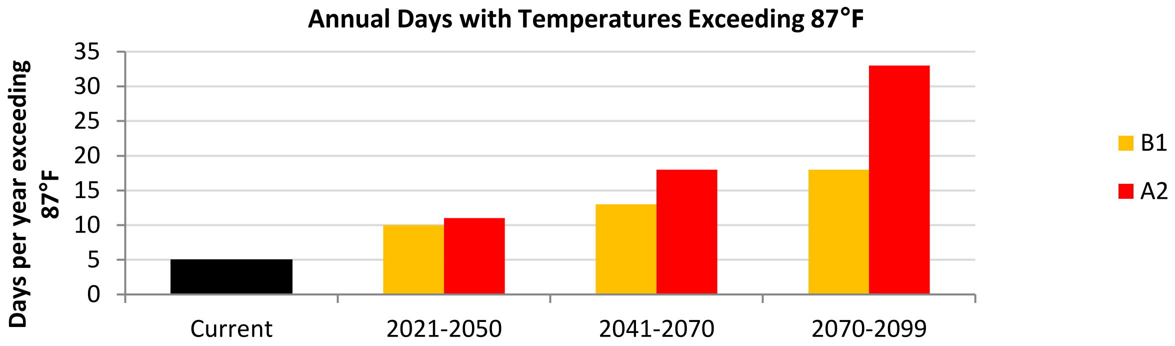


Figure 12: Number of days with temperatures exceeding 87 °F

Table 5: Date of first occurrence and longest number of consecutive days with temperatures exceeding 87 °F

	Date of first annual occurrence		Longest number of consecutive days	
Time slice	B1	A2	B1	A2
Current	20-Jun	20-Jun	2	2
2021-2050	13-Jun	13-Jun	4	4
2041-2070	10-Jun	5-Jun	5	6
2070-2099	4-Jun	22-May	6	11

Nightly temperatures are also projected to increase. For instance, the number of nights with minimum temperatures exceeding 64°F is projected to rise from about 5 per year at baseline to 32 per year by the end of the century under the A2 scenario. While Vermont-specific epidemiological analyses have not found a clear relationship between nighttime temperatures and health outcomes, such relationships have been found in other regions, including in regions of Quebec just north of Vermont.

2.3.3 Precipitation

The amount of precipitation falling in Vermont every year is projected to increase. The increase is not spread evenly across seasons, as shown in Figure 13, and is particularly pronounced in the winter and spring. Precipitation is a more complex phenomenon than temperature and behaves differently under the two emissions scenarios. Notably, the projected increase is higher under the B1 scenario and in fact, under the A2 scenario, precipitation actually declines over the summer months compared to the baseline.

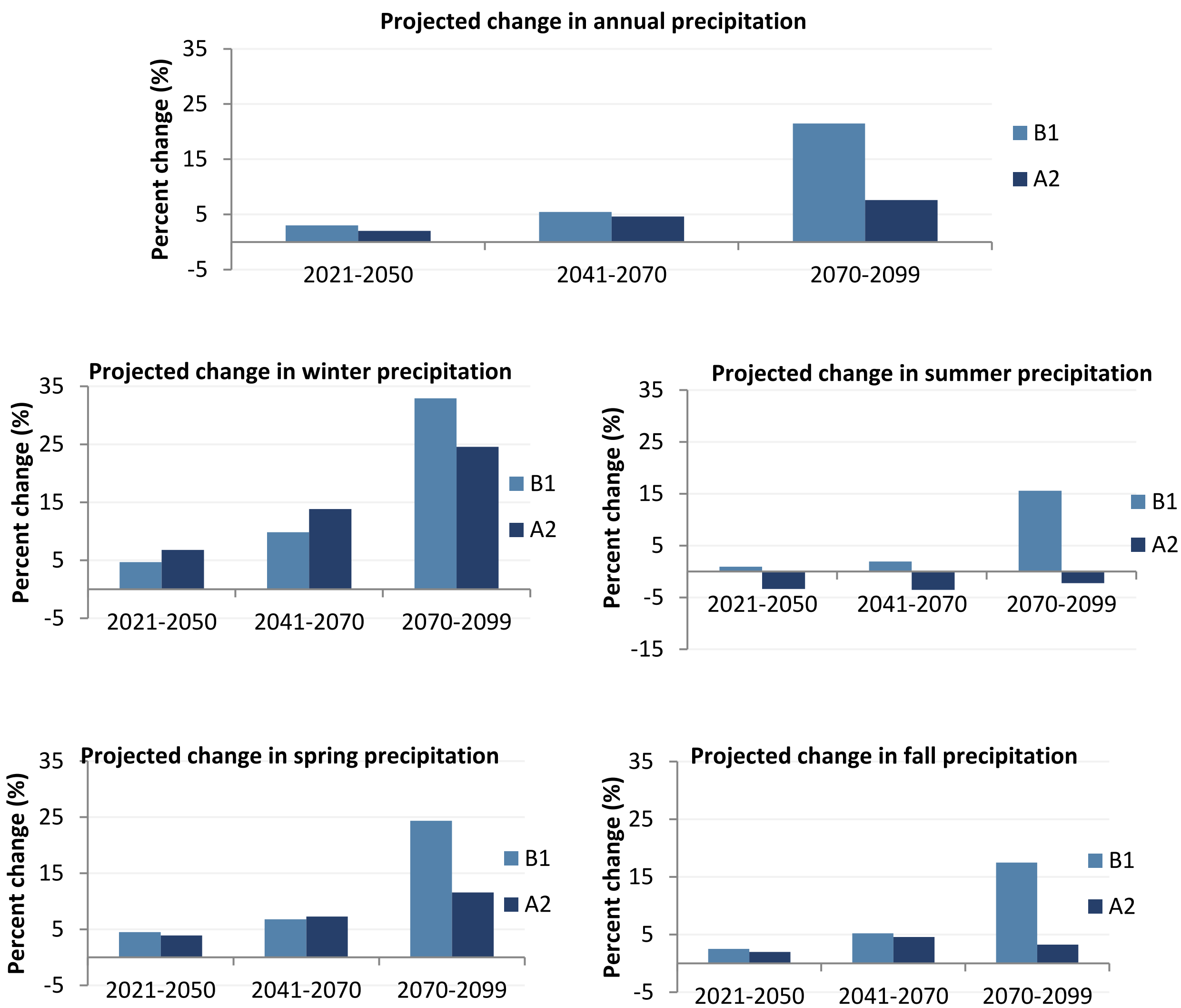


Figure 13: Projected cumulative annual and seasonal precipitation in Vermont

2.3.4 Extreme Precipitation

The occurrence of extreme precipitation events in Vermont is projected to increase. Figure 14 shows the increase in frequency of days with rainfall exceeding selected rainfall depths.

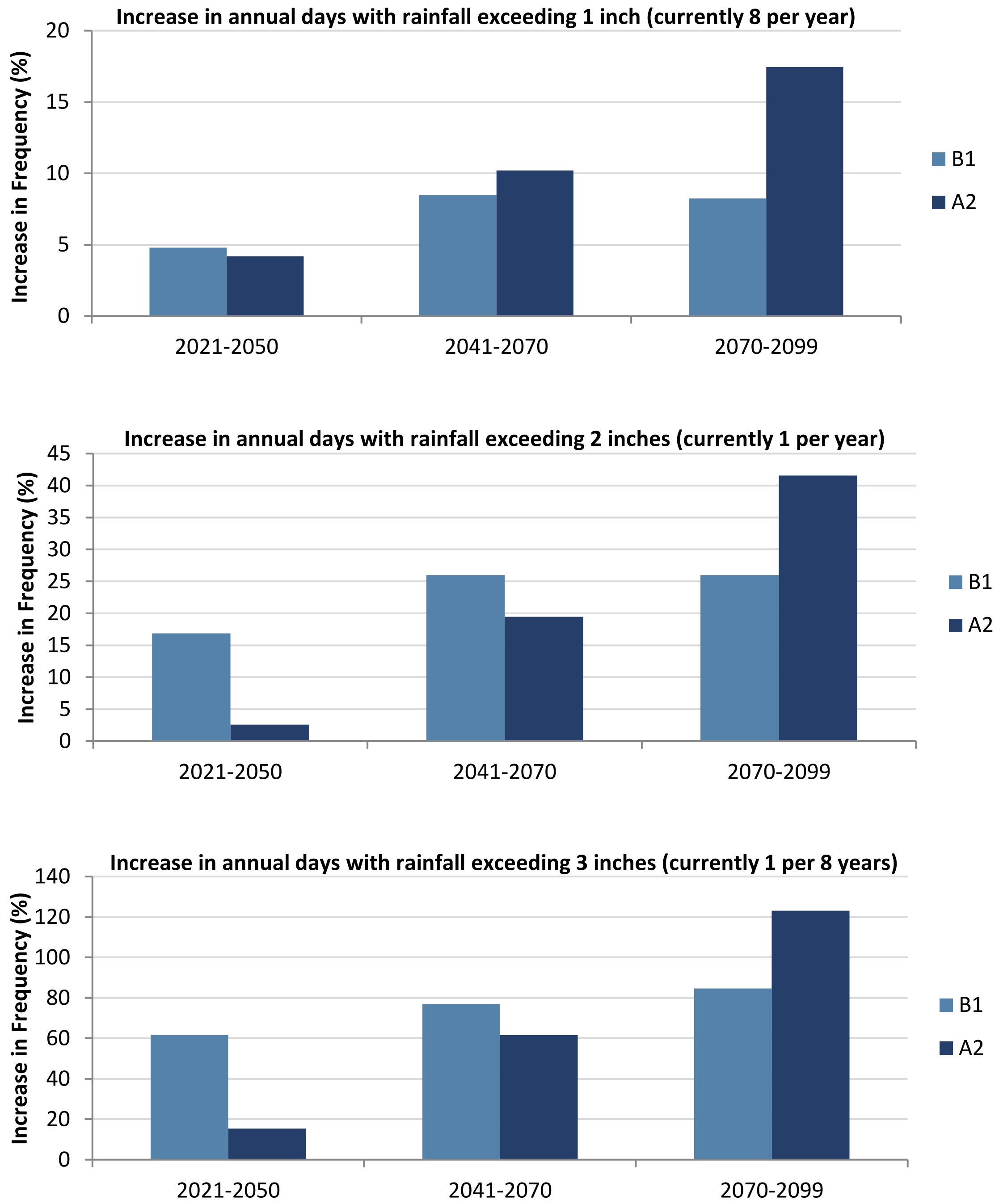


Figure 14: Increase in number of days with rainfall exceeding selected depths, compared to the 1981-2010 baseline.

Figure 15 displays this percent increase in frequency for the A2 scenario, but with all three rainfall depths shown on the same scale. Note how the increase in frequency becomes much greater with greater rainfall depths. In other words, the more extreme the rainfall, the more frequent it is projected to become as compared to its 1981-2010 baseline.

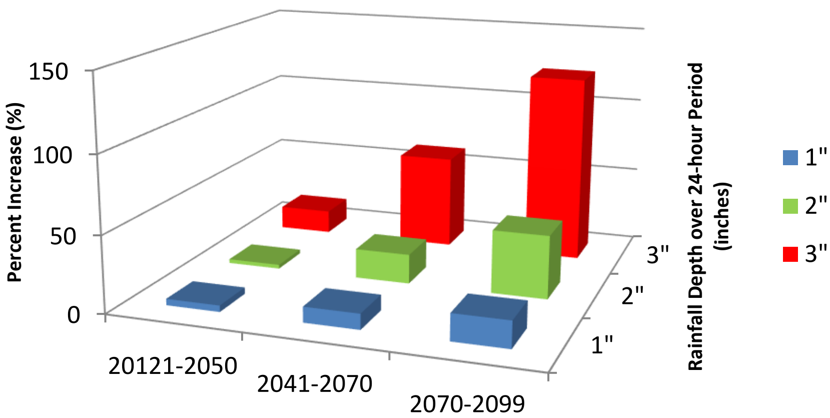


Figure 15: Percent increase in the number of days with rainfall exceeding selected extreme rainfall depths, compared to the 1981-2010 baseline, under the A2 scenario.

Table 6 illustrates how this pattern affects the return period for rainfall depths exceeding 3 inches. Such rain events, as averaged over the whole state, currently occur about once every 8 years. Under the A2 scenario, by the end of the century, rains exceeding 3 inches over a day are projected to occur about once every 3 years.

Table 6: Projected return period of daily rainfall exceeding 3 inches

Time Period	Rainfall exceeding 3 inches in 24-hours expected to occur every…	
	B1	A2
Current	8 years	8 years
2021-2050	5 years	7 years
2041-2070	4 years	5 years
2070-2099	4 years	3 years

The projections clearly show an increase in the frequency of extreme precipitation events. However, while GCMs are quite effective at projecting average indicators over 30-year time slices, they are not designed to predict rare events that might occur only a few times over a 30 year period, let alone once every 100 years. In other words, though the projected frequency increases with increasing rainfall depth, so does the uncertainty of the projection. This is why this report does not provide estimates of the occurrence of rainfall depths greater than 3 inches. The risk of the occurrence of important design storms such the 25, 50 and 100-year events is likely to increase, but predicting how many of such events would actually occur by the end of the century is not a worthwhile exercise given the current modeling limitations for such rare events.

A Note on Hurricanes and Tropical Cyclones

Catastrophic rainfall events are often associated with hurricanes or other tropical cyclones. Cyclonic events and their relationship to climate change are an important topic of research for climate scientists.

However, the nature of that relationship remains unclear. Globally, the number of tropical cyclones appears to have remained relatively stable since the 1960’s and projections are not in agreement about whether the number of hurricanes will increase in the future (Emanuel 2013). For instance, studies using the CMIP3 datasets as well as low emissions simulations with the CMIP5 dataset suggest a decrease in tropical cyclone activity globally and in the North Atlantic, though a recent study using CMIP5 output at a higher emissions scenario found an increase (Emanuel 2013). However, the destructive potential of Atlantic tropical cyclones, as measured by a mix of storm intensity, duration and frequency, appears to have increased over the century and particularly since 1970 (CCSP 2008). Most projection-based studies also agree on an increase in the intensity of North Atlantic hurricanes (CCSP 2008, Emanuel 2013). For instance, one study found that for each 1.8 °F increase in temperature, hurricane core rainfall is expected to increase by 6 to 18% (CCSP 2008). For a landlocked state such as Vermont, increasing hurricane intensity is of greater concern than frequency, since less intense hurricanes dissipate relatively soon after landfall and do not reach the state. Currently hurricane projections are not able to estimate the number of hurricanes that Vermont is likely to experience over the century with an acceptable level of certainty.

2.3.5 Dry Spells

The number of days with precipitation of less than 0.01 inches is not projected to change substantially over the century under either emissions scenario. The mean annual number and the longest annual number of consecutive dry days are also not expected to change substantially. For instance, under the A2 scenario, by the end of the century, the longest annual number of consecutive dry days is expected to rise from about 13 to about 14 days. It should be noted however that under the A2 scenario, cumulative rainfall over the summer months is projected to decrease somewhat. Exceptionally severe droughts that have historically occurred once every several decades cannot be reliably simulated by global climate models.

2.3.6 Snowfall and Ice-storms

The number of days with snow is projected to decrease substantially over the century under both emissions scenarios while the ratio of liquid precipitation to frozen precipitation is expected to rise, as summarized in Table 7. However, the data in the table does not address snowfall depth or ice-storms. There have in fact been few projection studies on the future occurrence of heavy snowfall and ice-storms in the United States (CCSP 2008). One of these studies looked at heavy snowfall in the Great Lakes region and found a local decrease, but a corresponding downwind and northern increase (CCSP 2008), though the study’s applicability to Vermont is not clear.

Table 7: Number of days with snow and annual ratio of liquid to frozen precipitation

	B1		A2	
Time slice	Days with snow	Ratio liquid: frozen	Days with snow	Ratio liquid: frozen
Current	23	12	23	12
2021-2050	20	13	17	18
2041-2070	18	18	13	23
2070-2099	16	20	8	44

Stopping the Clock

In 1914, the world was very different from how is today. The First World War began, women in this and most other countries were not yet allowed to vote and the airplane was in its infancy. More pointedly, antibiotics were new, the world's population was about a quarter of what it is today and malaria was a major health concern in much of the country. By the end of this century, many things other than the climate will change. Many of these changes will impact health and will interact with climate. Will we be able to address the threat of antibiotic resistance? Will we spiral into a major armed conflict? Will our population have doubled, or will it be smaller than it is today? How will land use patterns change? The purpose of the CHPR is not to address all of these possibilities, but rather to attempt to isolate the health impacts of climate change alone. To do so, it assumes a world that is relatively unchanging, except for continued increases in the concentration of heat-trapping gases in the atmosphere and the associated warming of the climate system. While the assumption of an unchanging world is unlikely, it helps us view climate and health impacts against the same scales that we use to gauge our current health priorities.

Photo: Vermont Historical Society

3. Linking Climate Impacts and Health Exposures

The following section draws links between the changes expected in Vermont's climate, as described in Section 2, and exposures of public health concern. It describes the mechanisms by which climate and health impacts might occur and makes an assessment of each exposure's likelihood to change in a *meaningful* way in Vermont. *Meaningful* in this context does not necessarily imply statistical significance; while the section draws upon available data, these initial assessments are largely qualitative. The term *meaningful* is used, recognizing that the climate, and by extension climate change, affects almost *everything* that happens on this planet at least a little. Thus a *meaningful* change refers to one that would have sufficient impact to justify public health action.

The range of potential direct and indirect impacts of climate change on our health is extensive, as attested to by the ample scientific literature on the subject. Rather than perform its own in-depth literature review, the Department of Health drew on five existing reviews to create a list of potential climate impacts of human health concern in North America. The five reviews used to define the scope of health impacts to be examined were:

1) **Draft report of the Third National Climate Assessment (NCA):** *Chapter 9. Human Health.* The United States Global Change Research Program (USGCRP) is required by the *Global Change Research Act* to produce a National Climate Assessment every few years. The second NCA was published in 2009. The third NCA was published in May 2014. The Health Department

opted to use the draft of the third assessment rather than the second assessment because the former is not only more up-to-date, but contains a more in-depth review of potential health impacts. Chapter 9 of the draft NCA deals exclusively with such impacts and is based on a review of 2,668 articles, collected between January 2007 and May 2013.
Chapter 9 of the NCA report is cited throughout this text as (Luber et al. 2013)

2) **Report of the Interagency Working Group on Climate Change and Health (IWGCCH):** *A Human Health Perspective On Climate Change*
The IWGCCH is an ad hoc group formed by participating federal agencies and organizations at the invitation of the National Institute of Environmental Health sciences (NIEHS), National Oceanic and Atmospheric Administration (NOAA), Centers for Disease Control and Prevention (CDC), and Environmental Protection Agency (EPA). The report was published by the NIEHS and the journal Environmental Health Perspectives.
The report of the IWGCCH is cited throughout this text as (Portier et al. 2010)

3) **Report of the State Environmental Health Indicator Collaborative (SEHIC):** *Environmental Health Indicators of Climate Change for the United States*
SEHIC was established by the Council of State and Territorial Epidemiologists (CSTE) to develop indicators of the health impacts of climate change.
SEHIC's report is cited throughout the text as (English et al. 2009)

4) **National Center for Environmental Health (NCEH)/Agency for Toxic Substances and Disease Registry (ATSDR):** *Climate Change: The Public Health Response*
This article, published in the American Journal of Public Health, describes the role of public health in the context of the climate change. It was drafted by staff at the NCEH and ATSDR, both of which fall under the CDC umbrella.
The NCEH/ATSDR article is cited throughout the text as (Frumkin et al. 2007)

5) **Health Canada:** *Human Health in a Changing Climate*
The report outlines the anticipated impacts of climate change on the public health in Canada. This report was deemed relevant to the Health Department's own assessment due to Vermont's proximity to Canada. The report contains a section specific to southern Quebec, which lies on Vermont's northern boundary.
The Health Canada report is cited throughout the text as (Belanger et al. 2008)

A total of 14 potentially climate-change sensitive health exposures were drawn from the five reports. These are summarized in Table 8. Each of the impacts in the table is further examined for its relevance to Vermont in Sections 3.1 to 3.13.

Table 8: Potential climate change related health exposures in North America, as drawn from five reviews of climate change and health impacts. "Yes" indicates that the exposure was mentioned in that publication.

Climate Change Related Health Exposures	NCA (Luber et al. 2013)	IWGCCH (Portier et al. 2010)	SEHIC (English et al. 2009)	NCEH/ ATSDR (Frumkin et al. 2007)	Health Canada (Belanger et al. 2008)
Impacts on air quality	Yes	Yes	Yes	Yes	Yes
Extreme heat events	Yes	Yes	Yes	Yes	Yes
Extreme weather events	Yes	Yes	Yes	Yes	Yes
Vector-borne and other infectious pathogens	Yes	Yes	Yes	Yes	Yes
Foodborne and waterborne pathogens	Yes	Yes	Yes	Yes	Yes
Harmful algal blooms (including cyanobacterial)	Yes	Yes	Yes	Yes	Yes
Food insecurity	Yes	Yes		Yes	Yes
Threats to mental health	Yes	Yes		Yes	Yes
Exposures from mitigation technologies		Yes			
Population dislocation		Yes		Yes	Yes
Civil conflict		Yes		Yes	Yes
Ice –related hazards					Yes
Sea-level rise	Yes	Yes	Yes	Yes	Yes
Stratospheric ozone depletion		Yes			Yes

3.1 Air Quality Impacts

Climate change is expected to have adverse effects on North America's air quality (Belanger et al. 2008; English et al. 2009; Frumkin et al. 2007; Luber et al. 2013; Portier et al. 2010). Five components of air quality and their sensitivity to changes in the climate are discussed here. These five components are:

1) Ground-level ozone
2) Particulate matter (PM)
3) Wildfire smoke
4) Aero-allergens
5) Volatile and semi-volatile organic compounds (VOCs)

3.1.1 Ground-level ozone

Ozone is a colorless gas. Ozone occurs naturally, high-up in the stratosphere, where it protects human health by absorbing harmful ultraviolet radiation (EPA 2009). However, air pollutants from vehicles or industrial activity can react with sunlight to form ozone at ground level. When ground-level ozone is inhaled, even in fairly low amounts, it can irritate the respiratory system, cause cough and throat soreness, reduce lung function and inflame and damage the lining of the lungs, in turn increasing the risk of infection. Furthermore, ozone can aggravate asthma and other chronic respiratory diseases and over the long term, can cause permanent lung damage (EPA 2009).

The 2008 primary and secondary National Ambient Air Quality Standards (NAAQS) for ground-level ozone are 75 parts per billion (ppb) as averaged over an 8-hour period (known as the MDA8 (EPA 2013a). However ground-level ozone concentrations have been associated with health impacts at concentrations lower than this standard. For instance, even below an MDA8 of 60 ppb, increases in ground-level ozone are associated with increased respiratory hospital admissions, emergency department visits and physician visits (EPA 2013a). Increases in respiratory-related mortality have been noted at MDA8s below 63 ppb (EPA 2013). Health effects of long-term exposure to ozone have also been observed at levels below the current standard and have included elevated asthma hospital admissions at MDA8 below 41 ppb (EPA 2013). The 2008 ground-level ozone standard is currently being revised. The Clean Air Scientific Advisory Committee's (CASAC) has been advising, since before the development of the 2008 standard, that an MDA8 between 60 and 70 ppb would be more appropriate than the 75 ppb currently in use (EPA 2007).

The Vermont Department of Environmental Conservation has taken hourly ozone measurements at Bennington and Underhill since 1993. Ground-level ozone concentrations have fallen over this time period. Vermont is now one of the few States in the nation to be in compliance with the 2008 NAAQS of 75 ppb. However, MDA8 ozone concentrations do enter the 60-70 ppb range that has been recommended for the new standard. Thus Vermont may struggle to attain compliance due to the change in standard alone, even without considering the impact of climate change. More importantly, this means that despite currently being in compliance, Vermonters are nevertheless experiencing ozone-related health effects.

The effect of climate change on ozone concentrations in Vermont is difficult to estimate, because of the complex mechanism of ozone formation. The amount of ground-level ozone is determined by several interacting and sometimes competing chemical reactions. Generally, warmer temperatures increase the rate of ozone formation so long as there are sufficient precursors available. However, increases in moisture accelerate the rate of ozone decomposition and thus decrease ozone concentrations (Jacob and Winner 2009). In the Northeast, climate change is expected to lead to both higher temperatures and moister air. As a result, in areas with few ozone precursors, ozone levels are expected to go down (IPCC 2013). However, in areas that have higher concentrations of precursors, for instance urban areas, the amount of ground-level ozone is expected to go up (Jacob and Winner 2009). Ozone and ozone precursors can however be transported over long distances, such that rural areas can be affected by upwind urban areas. The situation is further complicated by stagnation events, described in the note below. Stagnation events can trap ozone and other pollutants over an area, resulting in spikes in pollutant concentrations. Stagnation events may increase in some areas with the changing climate (Portier et al. 2008), but an increasing trend has not been observed in Vermont to date.

Several attempts have been made to model changes in ground level ozone with the changing climate by linking chemical transport models (CTMs) with general circulation models (GCMs) (Jacob and Winner 2009). A summary of such modeling attempts for the eastern and northeastern United States is shown in

. While the effects of climatic warming on ozone concentrations are less clear in other parts of the country, in the Northeast, models have been consistent in predicting an increase. The magnitude of the predicted increase is fairly similar across models, in the range of 4 to 8 ppb (Jacob and Winner 2009). However, the modeled increases in ozone with warming temperatures have been observed in areas where ozone concentrations are in excess of about 60 ppb (Jacob and Winner 2009). Below these concentrations, the correlation of ozone with increasing temperature is not clear and may even be an inverse relationship.

Vermont poses a challenge for predictions in that its ground-level ozone concentrations rarely exceed 60 ppb. Thus it is not clear whether Vermont's changing climate will result in more or less ozone then currently seen. Furthermore, Vermont lies at the northern boundary of the highly urbanized northeastern areas used in the GCM studies. Much of Vermont's ozone already comes from urban areas further south, so even if ozone formation over Vermont decreases, more ozone may be blown-in from other regions (personal communication, Richard Poirot (VT DEC): 8 Apr 2014). If ozone concentrations do increase in Vermont in the future, potential health effects include reduction in lung function and premature mortality.

Stagnation Events

Air stagnation events occur when air is trapped by poor ventilation due to persistent light or calm winds and by the presence of an inversion (Wang and Angell, 1999). In an inversion, cold air is trapped by a layer of warmer air.

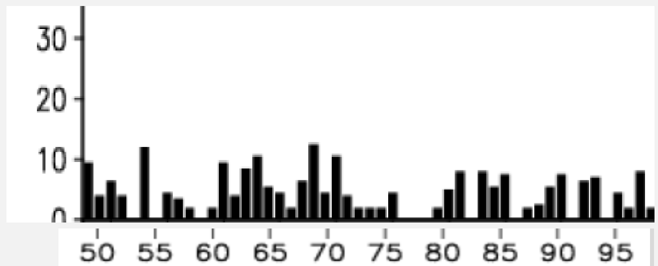


Figure 16: Total number of days of stagnation per year, for Vermont, 1948 to 1998 (adapted from Wang and Angell 1999)

Stagnation events are problematic from a public health perspective in that they can trap air pollutants. The changing climate may result in an increasing frequency of stagnation events in some areas (Portier et al. 2008). However, in Vermont, the annual number of days under a stagnation event appears to have decreased somewhat in recent decades.

Table 9: Linked Chemical Transport Model and General Circulation Model Studies of the Effect of Climate Change on Ozone Air Quality (Adapted from Jacob and Winner 2009)

Reference	Emissions Scenario	Time Horizon	Metric Reported	Notes	Surface Ozone Change
Hoegrefe et al. (2004)	A2	2050	JJA* MDA8**	50 eastern US cities	+4.4 ppb
Hoegrefe et al. (2004)	A2	2020, 2050, 2080	JJA MDA8	Eastern US	+2.7 ppb, +4.2 ppb, +5.0 ppb
Liao et al. (2006)	A2	2100	July mean	Northeastern US	+4 to +8 ppb
Murazaki and Hess (2006)	A1	2090	JJA MDA8	Eastern US	+2 to +5 ppb
Racherla and Adams (2006)	A2	2050	Summer mean	Eastern US	+1 to +5 ppb
Kunkel et al. (2007)	A1FI B1	2090	JJA MDA8	Northeastern US	+10 to +25%, 0 to +10%
Tagaris et al. (2007)	A1B	2050	JJA MDA8	Northeastern US	+2.8%
Avise et al. (submitted for pub.)	A2	2050	July MDA8	Northeastern US	+4 ppb

**JJA: June, July, August*
***MDA8: maximum daily 8-hour average*

3.1.2 Particulate matter

Airborne particulate matter (PM) is usually a mixture of solid particles and liquid droplets (EPA 2009). Particles that are emitted directly into the atmosphere are known as primary PM while those that condense from gas precursors are known as secondary PM. PM is categorized into coarser particles of diameter 2.5 to 10 µm (PM_{10}), fine particles of diameter 0.1 to 2.5 µm ($PM_{2.5}$) and ultrafine particles of diameter less than 0.1 µm ($PM_{0.1}$) (EPA 2009). Fine and ultrafine particles are of greatest concern to health as they can penetrate deep into the lung and can even enter the bloodstream (EPA 2009). Exposure to particulate matter can cause cardiovascular effects, respiratory effects and premature mortality; it has also been linked with adverse reproductive and developmental outcomes, cancer, mutagenicity and genotoxicity. The EPA has developed health-based standards for $PM_{2.5}$ and PM_{10}. These are summarized in Table 10. As of yet, there is not a separate standard for $PM_{0.1}$.

Table 10: 2012 Particulate Matter Standards (Adapted from EPA 2013)

Type	Standard μg/m^3	Measurement Period
$PM_{2.5}$	12	Annual arithmetic mean, averaged over 3 years
$PM_{2.5}$	35	24-hour average, 98th percentile, averaged over 3 years
PM_{10}	150	Not to be exceeded more than once per year on average over a 3-year period

Primary particulate matter

Sources of primary PM are varied but include fossil fuel and biomass combustion from stationary and mobile sources, industrial processes, smelting and other metallurgical processes, tire wear, prescribed burns and wildfires, fugitive dust from roads, erosion and entrainment of soils from either natural or disturbed areas and bioaerosols such as plant and insect fragments, fungal spores and pollen (EPA 2009). Among these sources, wildfire smoke, fungal spores and pollens, and erosion and entrainment of soils are likely to be climate-sensitive. The first two are discussed in their own dedicated sections. Airborne dust from entrained soils is discussed below.

Airborne dust

Airborne dust contributes to primary PM concentrations. Dust tends to be coarser than $PM_{2.5,}$ but this does not mean it is innocuous. One recent study for instance found that exposure to elevated concentrations of coarse dust in rural areas rapidly lead to increases in blood pressure and could thus be elevated with acute cardiovascular events (Brook et al. 2014). Additionally, airborne dust has been identified as a carrier of disease, including fungal coccidioidomycosis, or "valley fever" in the Southwest (Portier et al. 2008). A greater frequency of drought in some parts of the country is expected to result in higher levels of airborne dust (Belanger et al. 2008; Portier et al. 2010). For instance, based on output from 19 models under the A1B emissions scenario, the level of aridity that the Southwest experienced during the 1932 to 1939 and the 1948 to 1950 droughts are projected to characterize the new climatology of that region over this century (Seager et al. 2007).

As seen in Section 2.3.5, it is not clear that drought will become more common in Vermont itself and thus locally-sourced dust is not expected to increase substantially. That said, air quality in the Northeast can be impacted by droughts in other regions of the country. Most famously, the Dust Bowl years of the 1930's (Figure 17) saw large amounts of soil carried across the continent, resulting in brown snowfall over Vermont (Robinson 1936). However, the agricultural practices of that time were major contributors to these extreme dust storms (Cook et al. 2009). In fact, the drought that the Southwest experienced in the 1950's saw a greater

Figure 17: Dust storm near Dalhart Texas, 1935 (NOAA, George E. Marsh Album).

reduction in rainfall than that of the Dust Bowl era, but did not have such far-reaching air quality impacts due to the erosion control measures that has been implemented since (Seager et al. 2007). This does not dismiss the potentially devastating effects of drought on the Southwest, but it does suggest that air quality impacts in the Northeast from drought events in that region may be limited. Nevertheless, Vermont is not immune to the effects of disastrous droughts and wind events further afield. For instance, Saharan dust was transported to Vermont in 2008 (personal communication, Richard Poirot (VT DEC): 8 Apr 2014).

Secondary particulate matter

In general, about half of $PM_{2.5}$ forms from the reaction or condensation of precursor gases such as sulfur dioxide (SO_2), nitrogen oxides (NOx), volatile organic compounds (VOCs) and ammonia (NH_3) (Belanger et al. 2008). The precursor gases of secondary PM are emitted by fossil fuel combustion, motor vehicle exhaust, sewage treatment, animal husbandry, prescribed burns and wildfires and certain industrial processes, as well as volcanic activity, lightning and decaying vegetation (EPA 2009).

Projections of secondary particulate matter concentrations with warming temperatures are less consistent than for ground-level ozone (English et al. 2009). Health Canada modeled the impact of a 7.2°F increase in temperature on $PM_{2.5}$. It found an overall increase in average daily maximum $PM_{2.5}$ of 2% over the modeled baseline (Belanger et al.2008). Furthermore, the duration of exceedances over the Canadian standard of 30 µg/m3 increased by about 7% over baseline. However, in many industrial areas of Canada, particularly in the Quebec-Windsor corridor, the total number of exceedances actually decreased. For this reason, in the ensuing health assessment of climate impacts on $PM_{2.5}$, Health Canada calculated a decrease in mortality and morbidity due to this decrease in particulate peaks in the country's most populated areas (Belanger et al 2008). In their literature review, Jacob and Winner did not find any reported statistically significant correlations between historic records of PM and temperature (Jacob and Winner 2009). Attempts at modeling changes in PM in polluted areas using coupled General Circulation Models (GCM) and Chemical Transport Models (CTM) show changes ±0.1 to 1 $\mu g/m^3$ in mean annual $PM_{2.5}$ (Jacob and Winner 2009). While an increase of 1 $\mu g/m^3$ in mean annual $PM_{2.5}$ could have some health risks, the lack of agreement across studies on whether there will in fact be an increase or decrease of this magnitude, including in regions close to Vermont, makes conclusions about changes in secondary $PM_{2.5}$ in Vermont speculative at this stage.

3.1.3 Wildfire smoke

Wildfires can create large amounts of smoke, containing primary particulate matter as well as carbon monoxide, nitrogen oxides, and various volatile organic compounds (Luber et al. 2013). This smoke can impact air quality over extensive areas. The documented health impacts of wildfire smoke include: increased respiratory and cardiovascular hospitalizations; emergency department visits for asthma, bronchitis, chest pain and chronic obstructive pulmonary disease; respiratory infections; medical visits for lung illnesses and premature death (Luber et al. 2013)

Climate change appears to have already contributed to a global increase in wildfire frequency (Luber et al. 2013). The changing climate is expected to continue increasing the risk of wildfires (Belanger et al. 2008, English et al. 2009, Luber et al. 2013). This increase in risk is driven by the drying-out of already arid areas and to some extent, by increased rainfall in some areas which results in an increase in combustible biomass (Moritz et al. 2012). Moritz et al. used GCMs, under the A2 scenario, to develop a global map of predicted wildfire risk. This modelling effort statistically correlated satellite counts of wildfires with temperature and precipitation records to develop a climate-fire risk relationship. This relationship was then applied to GCM output. The findings are summarized on the maps in Figure 18. The model predicts that 32% of the world's landmass will experience an increase in the risk of wildfire over the next 30 years, with this proportion rising to 62% by the end of the century (Moritz et al. 2012). About 20% of the world's landmass is projected to experience a decrease in the probability of wildfires by the end of the century, while 18% show little change (Moritz et al. 2012).

Vermont itself currently sees about 100 wildfires every year (NIFC 2013). According to the Moritz et al. study described above, Vermont's wildfire risk is expected to remain stable. However, Vermont's air quality has historically been more affected by large out-of-state fires than fires burning in Vermont. Central Quebec, which has been a source area for some of Vermont's worst smoke events, is projected to experience a decrease in wildfire risk (Moritz et al. 2012). However, fire risk is expected to increase in the upper reaches of northern Quebec and in the western United States and western Canada. These source areas are at some distance from Vermont, but air quality may still be impacted by increases in fire risk there. Perhaps of greater concern to Vermont air quality is a smaller but closer increase in fire risk in nearby Maine, New Brunswick and Nova Scotia (Moritz et al. 2012). It should be noted however that the Moritz et al. modeling effort saw substantial disagreement between the various GCM model results, particularly for much of Quebec. Furthermore, other fire modeling efforts have differed somewhat with the Moritz et al. study as well as with each other (Moritz et al. 2014). In short, projecting fire risk is a difficult endeavor and at this time, conclusive assertions about wildfire smoke trends in Vermont over the coming decades is premature.

Combustion of Woody Biomass

The combustion of woody biomass for heat or power can have value as a climate change adaptation and mitigation measure. Wood stoves strengthen the resilience of households in the face of extreme weather events and associated power outages, as demonstrated by the increase in popularity of wood stoves in Quebec after the devastating ice storm of 1998 (Belanger et al. 2008). Additionally, biomass is a renewable and, if harvested properly, a low-carbon source of energy (Biomass Energy Development Working Group 2012). However, the combustion of biomass has its downsides. Wood smoke contains significant quantities of compounds known to be dangerous to human health (Naeher et al. 2007). $PM_{2.5}$ is a widely used indicator of wood smoke, and can have negative impacts on cardiovascular, cerebrovascular, and respiratory health. Vermont's highest $P.M_{2.5}$ concentrations occur on winter evenings, a result of smoky wood stoves. Furthermore, wood smoke is a source of black carbon, which accelerates warming over the short-term by absorbing energy from sunlight (EPA 2012). As Vermonters continue to search for optimal ways to mitigate and adapt to the changing climate, the value of the various mitigation options will have to be weighed against the potential costs.

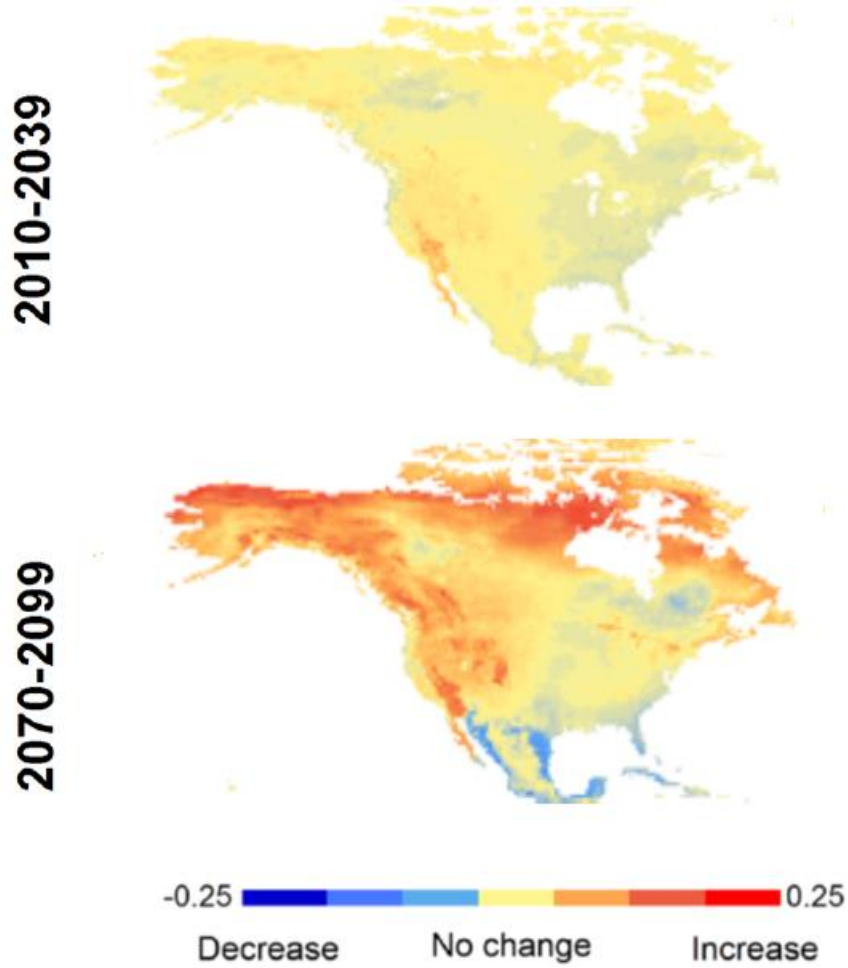


Figure 18: Change in fire probability in North America, based on correlations between satellite measures of wildfires and climate indicators, projected into the future using GCM output under the A2 scenario (adapted from Moritz et al. 2012)

3.1.4 Aero-allergens

Allergens elicit a strong and potentially harmful immune response in a subset of susceptible people. The two main categories of aero-allergen of concern with regards to their relationship to climate change are pollens and molds.

Pollen

Pollens are among the most common allergens (NIAID 2012). Pollens consists of microscopic grains that sometimes clump together to form visible clusters (NIAID 2012). Allergic reactions to pollen usually include runny nose and congestion, sneezing and itchy, red and watery eyes (NIAID 2012). Pollen can also be a trigger for some types of asthma (Beggs and Bambrick 2005). Elevated pollen concentrations and longer pollen seasons increase allergic sensitizations as well as the frequency and severity of asthma episodes (Luber et al. 2013). As a result, they diminish productive work and school days (Luber et al. 2013). Allergic responses to pollen can be further exacerbated by simultaneous exposure to other air pollutants (Luber et al. 2013).

There are three distinct aeroallergen seasons in North America: tree pollen in the spring, grass pollen in the early summer and weed pollen in the summer and fall (Ziska et al. 2011). A variety of plant pollens have been identified as allergens, though population sensitivity varies by the type of pollen. Allergy to ragweed pollen is the most common of pollen allergies in North America affecting an estimated 36 million Americans (Ziska et al. 2012).

The changing climate will likely result in increased exposure to plant allergens (Belanger et al. 2008; English et al. 2009; Frumkin et al. 2007; Luber et al. 2013; Portier et al. 2010). This will occur through both the lengthening of the pollen season and increased production of pollen due to higher concentrations of carbon dioxide (Luber et al. 2013). Several studies have demonstrated changes in the phenology of plants as a response to climate change (Ziska et al. 2011). Some plants, like birch, for instance, have been found to flower earlier, but the total length of their pollen seasons remain relatively unchanged (Ziska et al. 2011). However, ragweed pollen concentrations measured by the National Allergy Bureau in the United States and Aerobiology Research Laboratories in Canada show a lengthening of the weed's pollen season over the 1995 to 2009 period (Ziska et al. 2011). This increase is differentiated by latitude, with northern locations experiencing a greater lengthening. While locations in Texas and Oklahoma may not have experienced a noticeable change in pollen season length, Fargo, North Dakota and Minneapolis, Minnesota saw their pollen seasons lengthen by an average of 16 days over the 16-year study period (Ziska et al. 2011). Figure 19 summarizes these findings and shows the close association between the lengthening of pollen season change in first frost of the year. Note that ragweed does not generally flower until after June 21st, a mechanism triggered by hours of sunlight. This mechanism

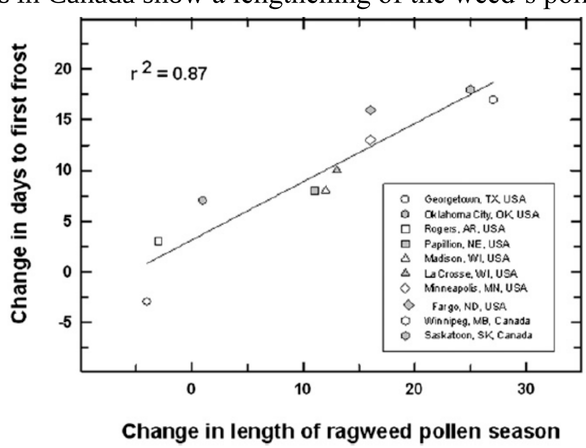


Figure 19: Change in the length (days) of ragweed pollen season from 1995 to 2009 as a function of change in days to first frost for 10 central North American locations (Adapted from Ziska et al. 2011)

restricts how much earlier flowering can occur, but the extension of the pollen season is largely determined by temperature. (Ziska et al. 2011)

Additionally, ragweed pollen production has been found to increases with increasing carbon dioxide concentrations (Luber et al. 2013). Laboratory tests, simulating carbon dioxide concentrations in the years 1900 and 2000, and anticipated concentrations by 2075 under the A2 scenario, showed a doubling of pollen production over the last century and a further doubling by 2075 (Luber et al. 2013). Figure 20 summarizes these findings. While an increase in pollen production and a lengthening of the pollen season for at least some plant species appear likely, the health impacts of this increase in pollen are less clear (Beggs and Bambrick 2005). For instance, the prevalence and severity of asthma has increased over the last few decades, a phenomenon which may in part be the result of climate-driven mechanisms (Beggs and Bambrick 2005). However, more recently, several studies have found a plateauing in asthma prevalence globally, suggesting that there may be a somewhat stable proportion of the population that is genetically susceptible to the condition (Beggs and Bambrick 2005).

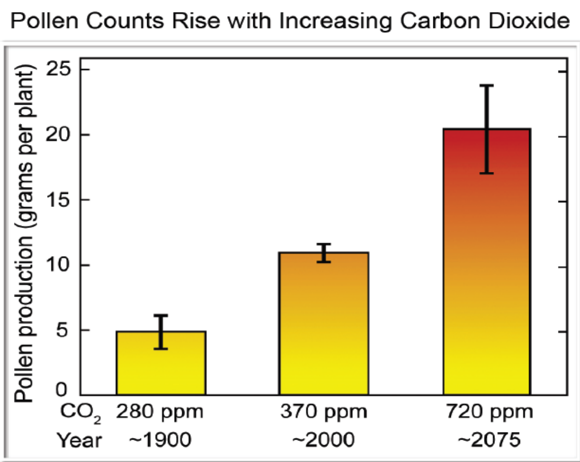


Figure 20: Pollen production in ragweed grown in chambers at carbon dioxide levels simulating past, current and projected atmospheric levels. (Adapted from Ziska and Caufield 2000, as cited in Luber et al. 2013).

Molds

Mold is a general term used to describe a type of fungus. While most people do not appear to be affected by everyday exposure to mold, when people allergic to mold inhale the spores, they can have a reaction that often includes runny nose, itchy eyes and sneezing. Mold grows under a fairly wide range of conditions, though most often in cool, damp places. Generally, mold spores take hold and grow at temperatures between 40 and 70°F and require about 70 percent or higher relative humidity. Where climate change results in appropriate temperatures, greater humidity and increased extreme rainfall, it may create a more favorable environment for the proliferation of molds (Luber et al 2013, Portier et al. 2010). Furthermore, mold can become a serious problem in buildings that have been flooded (CDC 2007a). Increases in flooding events would thus likely result in more Vermonters having to deal with mold. Data on the prevalence of residential or occupational mold in Vermont and its associated health burden is limited. The Health Department does however regularly receive calls requesting information on mold in homes. Not surprisingly, such calls peaked after the extensive flooding caused by Tropical Storm Irene.

Indoor dampness and mold exposure has been associated with the exacerbation of respiratory symptoms and asthma. This association has been demonstrated in infants, children, and adults (Douwes and Pearce, 2003). The Institute of Medicine (IOM) at the National Academies of Sciences, Engineering, and Medicine determined that there is significant evidence to link indoor exposure to mold with upper respiratory tract symptoms, cough, and wheeze in otherwise healthy people, and with the exacerbation of asthma symptoms among people with asthma (CDC 2014a).

3.1.5 Volatile organic compounds (VOCs)

Volatile organic compounds (VOCs) are comprised of a large group of chemicals, several of which are hazardous to human health (EPA 2012). While some are directly toxic, others contribute to the formation of ground-level ozone, which was discussed in section 3.1.1 (EPA 2012). With warming temperatures, the evaporation rate of most organic compounds is expected to increase (Portier et al. 2010). The Vermont Department of Environmental Conservation monitors several VOCs, including benzene, 1,3-butadiene, toluene, xylenes, and styrene. Generally, the concentration of toxic VOCs have been decreasing over the last few decades (personal communication, Richard Poirot (VT DEC): 8 Apr 2014) . In the context of this trend, it is not clear that the increase in temperatures expected in Vermont would result in an additional release of such compounds in a quantity that would substantially directly affect human health. Perhaps of greater concern is the potential effect that the warming climate might have on the release of isoprene and other VOC ozone precursors by vegetation, though there are many uncertainties associated with the relationship (Pacifico et al. 2009).

3.2 Extreme Heat Events

Extreme heat is the leading cause of weather-related deaths in the United States (CDC 2013a). From 1999 to 2009, there were about 7,800 deaths in the United States that were directly attributable to heat (CDC 2013a). These deaths account for close to a quarter of weather-related deaths in the nation (Figure 21). Unfortunately, this number is likely a severe underestimate of the true death toll from extreme heat events, as it only takes into account those deaths in which heat is explicitly listed as a cause or contributing cause of death on the death certificate. In practice, extreme heat increases the risk of death from cardiovascular, respiratory, cerebrovascular and other causes (Luber et al. 2013). Thus many heat-related deaths go unreported as such, though the total number of deaths during and immediately after an extreme heat event may be substantially higher than the seasonal average. Figure 21 shows the proportion of daily deaths over the average summer daily deaths from all causes in Montreal during July 2010. The heat wave that occurred at the start of month resulted in almost a doubling of daily deaths. Morbidity related to extreme heat events poses an additional health burden. Heat exhaustion and heat stroke are the most visible manifestations of this. From 2003 to 2009, in the May through September period, Vermont saw 18 hospitalizations and 496 emergency department visits explicitly for heat-related illness (EPHT 2013). However, like mortality, extreme heat events have been associated with increased hospital admissions for health outcomes not explicitly related to heat, including cardiovascular, kidney and respiratory disorders (Luber et al. 2013). In addition to mortality, Figure 22 also shows an increase in daily all-cause emergency department visits during Montreal's 2010 heat wave.

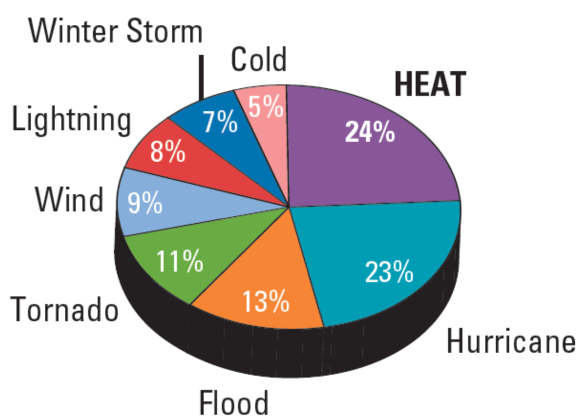
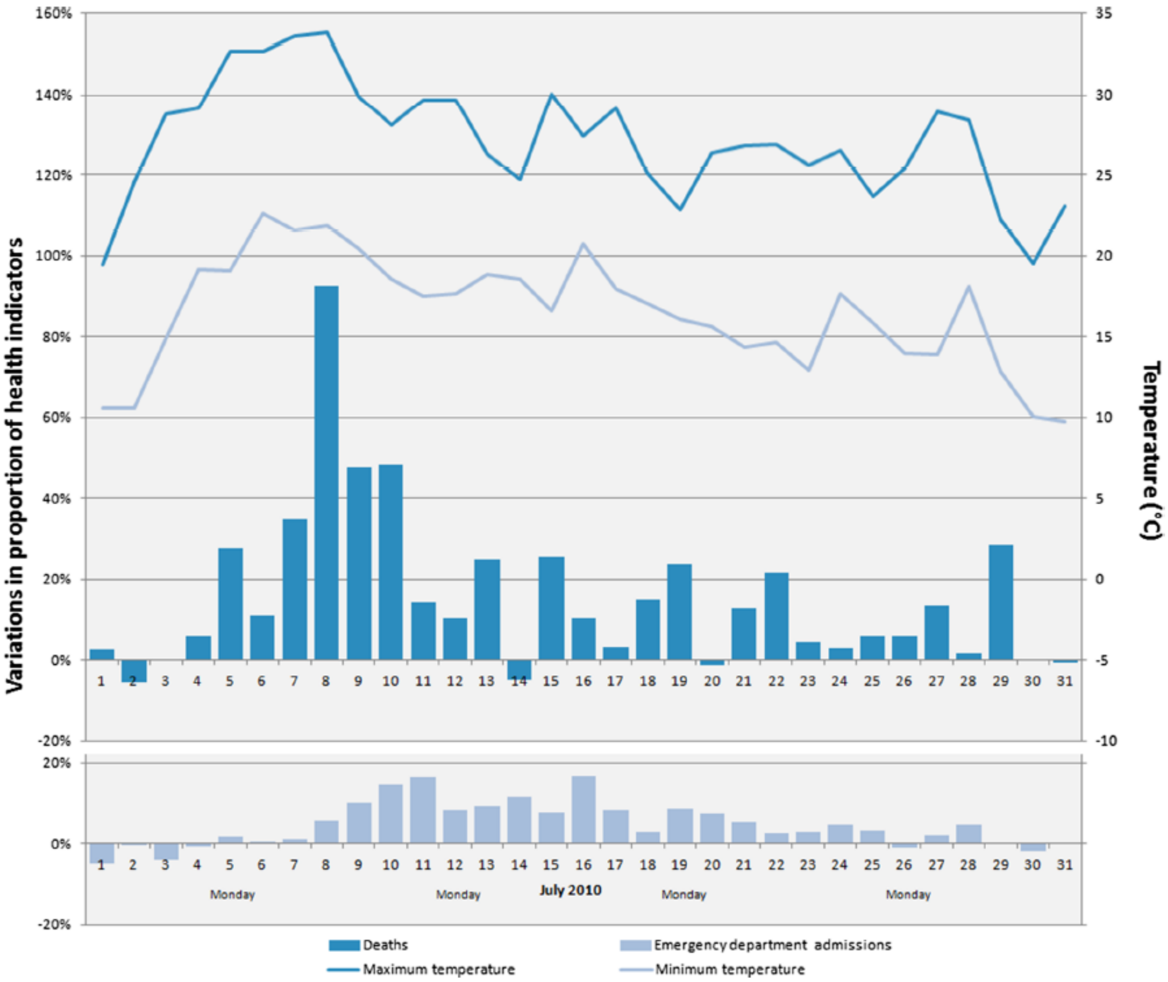


Figure 21: Deaths directly attributable to weather conditions, 2000 to 2009. Heat deaths include only those deaths where heat is listed as an underlying or contributing cause of death on the death certificate (CDC 2013a).

There is no widely accepted definition of what constitutes an extreme heat event, because the temperature threshold at which health effects begin varies by region. The heat-health relationship is to some extent attenuated by physiological acclimation in populations that are accustomed to warmer climates and by adaptations in housing, air-conditioning and lifestyle that these populations have developed over time. For instance, in New York City, analyses suggest that beyond a heat index threshold of between 95 and 100°F, excess mortality is detectable (Metzger et al. 2010). The heat index is a measure that incorporates



both temperature and humidity. However, further north in Montreal, a temperature of 91°F has been associated with detectable increases in daily mortality (Litvak et al. 2005). Not only is the threshold value different, but in that location, temperature alone rather than the heat index was found to be a more robust indicator. Epidemiological analyses by the Health Department suggest that there is an increase in Vermont's daily mortality on days when temperatures reach or exceed 87ºF. Furthermore, on these days, heat-related emergency department visits are eight times more frequent than they are on cooler days in the months from May to September.

Extreme heat events are expected to increase as the climate system warms (Belanger et al. 2008; English et al. 2009; Frumkin et al. 2007; Luber et al. 2013; Portier et al. 2010). Vermont currently experiences

Figure 22: Temperature, all-cause daily mortality and emergency department visits from eight of Quebec's health regions during the July 2010 heat wave. Maximum daily temperature is upper line (Bustinza et al. 2013)

about 5 such days above 87°F per year. Under the A2 scenario, the number of such days in Vermont is projected to climb to 18 by mid-century and to 33 such days by the end of the century. Without individual and systemic adaptation, such an increase would likely result in a corresponding increase in premature mortality and in heat-related morbidity.

The health benefits of a warmer Vermont?

Vermont is known for its harsh winters more so than for its hot summers. This leads to the question of whether there will be health benefits from a reduction in severe cold. Several researchers have quantified such health benefits in their regions. For instance, Belanger et al. demonstrated a decrease in cold-related deaths in Canada, although that decrease was substantially outweighed by an increase in heat related deaths (Belanger et al. 2008). However, while such calculations may be of use when gauging the costs and benefits of greenhouse gas emissions policies, they are not useful in designing adaptation strategies, which is the goal of this report. A reduction in cold-related morbidity and mortality does not remove the need to address an increase in heat-related morbidity and mortality.

3.3 Extreme Weather Events

Vermonters are justifiably concerned about possible changes in the frequency and severity of extreme weather events after having experienced or witnessing the devastating effects of Tropical Storm Irene in August 2011. Tragically, six Vermonters died directly as a result of the storm. The storm also permanently or temporarily displaced 1,405 households, resulted in drinking water advisories affecting 16,590 Vermonters, caused widespread power outages, led to a multitude of hazardous spills and disrupted over 500 miles of road (ANR 2011). Powerful rainstorms or snow storms can result in health risks through several pathways, including those listed below:

- Drowning from flooding;
- Drowning in swift currents in rivers and streams used for recreational purposes;
- Injury and death from falling trees and downed power lines;
- Increased risk of motor-vehicle crashes;
- Interruption of medical care due to power outages and other infrastructure disruption;
- Slips and falls following winter weather anomalies such as ice storms;
- Hypothermia or carbon-monoxide poisoning following power outages or fuel supply disruptions;
- Injuries related to clean-up activities following severe weather events, such as from improper use of chain-saws to remove fallen trees or falls during removal of snow from roofs;
- Psychological trauma from loss of loved ones or loss of property and displacement (addressed in section 3.8);
- Contamination of drinking water or food supplies (this issue is addressed separately in Section 3.5);
- Impacts on indoor air quality from mold following flooding (this issue was addressed in Section 3.1)

- Hazardous materials spills

While Tropical Storm Irene was a dramatic event that affected large swathes of the state, Vermont experiences severe but more localized disasters almost every year. Since 1984, the state has experienced 35 events that were declared as Major Disasters by the federal government. (FEMA 2016). Figure 23 shows the number of these disaster declarations each year since 1984. There has been an increase in declarations over the last 30 years, though disaster declarations themselves should be used with caution as an indicator of increased extreme weather events, as they may be mediated to some extent by administrative and political factors.

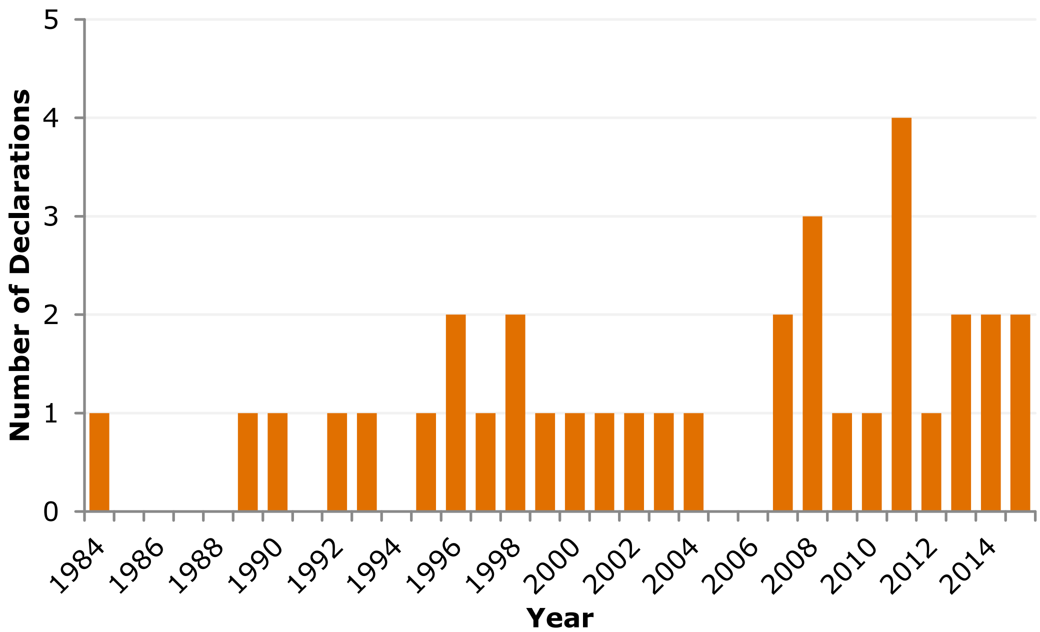


Figure 23: Disaster declarations in Vermont, 1984 to 2015 (data from FEMA 2016)

Figure 24 shows the seasonal distribution of these disasters, the majority of which occurred in the summertime. Of the 35 declarations, 29 (83%) had a flooding component, and the vast majority of these flooding events were directly related to heavy rainfall, as opposed to snowmelt (FEMA 2016).

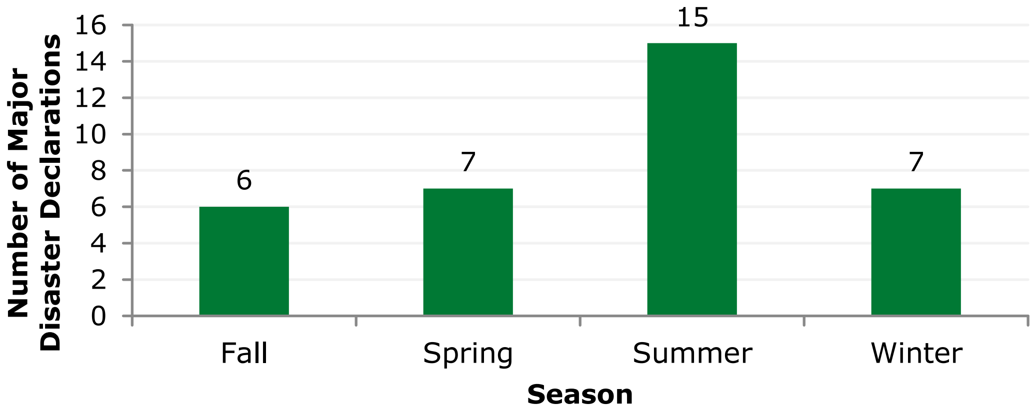


Figure 24: Vermont disaster declarations by season of year, 1984-2015 (FEMA 2016).

Disaster declarations do not capture all of the weather-related disasters that occur in Vermont. Unfortunately, more detailed information for smaller disasters is not readily available. Disaster declarations thus remain a useful indicator of the most damaging severe weather events and shed light on the nature of these threats and by extension, on how that threat might change with the changing climate.

Projected increases in extreme weather events and associated injuries are widely reported in the literature (Belanger et al. 2008; English et al. 2009; Frumkin et al. 2007; Luber et al. 2013; Portier et al. 2010). Given the threat posed by intense summer and fall rains in Vermont, the projected increases in extreme precipitation events in Vermont that were discussed in Section 2.3.4 are of high concern. The caveat to be reiterated is that the uncertainty of precipitation predictions increases with greater rainfall depths, because the occurrence of rare events are statistically more difficult it is to predict over a fixed time period. Table 11 shows the projected frequency and associated standard deviations for a range of heavy rainfall depths. Note how the standard deviation climbs with increasing depth. While the projected increase in the frequency of rainfall depths in the table below are fairly certain, predicting yet more extreme "catastrophic" events used as design storms is more difficult.

Table 11: Projected annual occurrence and standard deviations for selected rainfall depths, in B1 and A2 emissions scenarios.

	Rainfall Depth											
	1"				2"				3"			
	B1		A2		B1		A2		B1		A2	
	Freq	SD	Freq	SD	Freq	SD	Freq	SD	Freq	SD	Freq	SD
Current	8.13	2.98	8.13	2.98	0.77	0.84	0.77	0.84	0.13	0.32	0.13	0.32
2021-2050	8.52	3.18	8.47	3.16	0.9	0.96	0.79	0.83	0.21	0.43	0.15	0.35
2041-2070	8.82	3.35	8.96	3.35	0.97	1.02	0.92	0.94	0.23	0.46	0.21	0.42
2070-2099	8.80	3.19	9.55	3.42	0.97	0.97	1.09	1.08	0.24	0.45	0.29	0.55

Estimating future disease burden from severe weather events is complicated both by the uncertainty in the number of extreme events that Vermont may experience over the century and because of a lack of knowledge of the current health impacts of such events. Even the health impacts of a cataclysmic event like Irene have not been fully quantified, let alone that of the more localized disasters that are so frequent in Vermont. What is clear is that the Vermont will increasingly find itself in a state of uncertainty and heightened risk from extreme weather events, even if a precise estimate of the future number of catastrophic events is not quite within reach. It is also clear that Vermont already finds itself in a state of vulnerability. This vulnerability is likely to be aggravated by the projected increase in intense rainfalls that may not themselves be catastrophic but that will contribute to greater erosion and reduce resilience in the face of catastrophic events.

A Note on Swimming holes and Extreme Precipitation

On average, there are about 5 drownings in Vermont's natural waters every year. These include boating accidents and falls, though swimming/bathing appears to account for 80% of the drownings. While it is not clear how many or these deaths are attributable to swollen rivers following storms, such deaths are known to occur. The strength of currents and the depth of water can change rapidly in many of Vermont's favored swimming holes, turning what may have been a fun natural water park one day into a potent hazard the next. With the projected increase in extreme precipitation events, rapid changes in current strength and water depth will become more frequent. Therefore, in the absence of adaptation actions, the number of drowning deaths in Vermont is likely to rise.

3.4 Vector-Borne and other Infectious Diseases

An infectious disease is one that is caused by micro-organisms such as bacteria, viruses and parasites. A vector-borne disease is an infectious disease that is transmitted to humans by blood-feeding arthropods, including ticks, mosquitoes and fleas or in some cases by mammals (e.g. rabies). These transmitting Globally, the changing climate is expected to impact the spread of a range of infectious diseases, especially vector-borne diseases (Belanger et al. 2008; English et al. 2009; Frumkin et al. 2007; Luber et al. 2013; Portier et al. 2010). Climate impacts can do this either by altering the dynamics of existing disease in a region, or by facilitating the arrival of new diseases or the return of previously eradicated diseases (Belanger et al. 2008). Table 12 summarizes the infectious diseases mentioned in the five climate and health reviews described in Section 3. Note that a person can be infected with more than one of these diseases at the same time. The table excludes infectious diseases that are primarily foodborne or waterborne; these diseases are dealt with in Section 3.5.

Table 12: Vector-borne and other infectious diseases mentioned in five climate and health reviews.

Mosquito-borne
West Nile Virus
Eastern equine encephalitis
St. Louis encephalitis
Western equine encephalitis
La Crosse encephalitis
Dengue
Chikungunya
Yellow fever
Malaria
Rift Valley fever
Jamestown Canyon virus*
Tick-borne
Lyme disease
Anaplasmosis
Babesiosis
Ehrilichiosis
Powassan
Rocky Mountain spotted fever
Tularemia
Other arthropod-borne
Chagas disease (*Triatoma spp.* bugs)
Plague (Fleas; pneumonic plague can also be transmitted from infected mammals)
Mammal-borne
Bartonellosis
Rabies
Hanta virus
Leptospirosis
Q fever
Other environmental infectious diseases
Valley fever (coccidioidomycosis)
Anthrax

*Jamestown Canyon virus was not mentioned in the reviews but was added based on information from VT Department of Agriculture.

Infectious disease dynamics depend on a range of factors other than climate, including land use, human behavior, efficacy of healthcare services, population dynamics of vectors, population dynamics of intermediate hosts such as birds, deer, and rodents and the evolution of the pathogens themselves. The interaction of climate and infectious disease is thus infused with uncertainty (Luber et al. 2013). With these sources of uncertainty in mind, the diseases listed in

Table 13 were reviewed in greater depth and were placed into one of five threat categories:

1) Diseases that are already present in Vermont and that may be exacerbated by climate change;

2) Diseases that may spread to Vermont even without the contribution of climate change – their vectors are already present in Vermont or the surrounding states and provinces, whose spread to and transmission in Vermont could be exacerbated by climate change;

3) Diseases that rely on temperature-limited vectors that cannot currently establish themselves in Vermont, but that may be able to do so by the end of the century under the A2 (higher emissions) scenario;

4) Diseases that have competent vectors or may in the future have competent vectors in Vermont but that are unlikely to become established in Vermont despite a vector presence;

5) Diseases that may be present in Vermont or may spread to Vermont in the future but whose link with the climate changes expected in Vermont is tenuous.

Table 13: Threat classification of vector-borne and other infectious diseases

1) Diseases already present in Vermont that may be exacerbated by climate change	
Disease	**Competent vectors in Vermont**
West Nile Virus	Primarily mosquitoes from *Culex* but also from *Aedes, Anopheles, Culiseta, Ochleratus, Psorophora, Uranotaenia* genera
Eastern Equine Encephalitis	Primarily *Culiseta melanura* mosquito with bridge vector mosquitoes from *Aedes, Coquilletttidia*, other *Culiseta, Culex* and *Ochlerotatus* genera
Lyme Disease	Deer tick (*Ixodes scapularis*)
Anaplasmosis	Deer tick (*Ixodes scapularis*)
Babesiosis	Deer tick (*Ixodes scapularis*)
Tularemia	American dog tick (*Dermacentor variabilis)*
Powassan	Woodchuck tick (*Ixodes cookei*)
2) Diseases that may spread to Vermont even without the contribution of climate change, whose spread to and transmission in Vermont could be exacerbated by climate change	
Disease	**Competent vectors in Vermont or adjacent regions**
St. Louis Encephalitis	Primarily mosquitoes from *Culex* but also *Ochlerotatus* & *Psorophora* genera
Western Equine Encephalitis	Mosquitoes of the genus *Culex*
La Crosse Encephalitis	*Aedes cenereus* and *Ochlerotatus triseriatus* mosquitoes
Western Equine Encephalitis	Mosquitoes from the *genus Culex*
Ehrilichiosis	Lone star tick (*Ambylomma americanum*)
Rocky Mountain Spotted Fever	American dog tick (*Dermacentor variabilis)*
3) Diseases with vectors that may spread to Vermont by the end of the century under a higher emissions scenario	
Disease	**Vectors found in more southern areas of the United States**
Dengue	*Aedes aegypti* and *Aedes albopictus* mosquitoes
Chikungunya	*Aedes aegypti* and *Aedes albopictus* mosquitoes

4) Diseases that have competent vectors or may in the future have competent vectors in Vermont, but are unlikely to become established in Vermont despite a vector presence	
Disease	**Vector**
Yellow Fever	Primarily *Aedes aegypti* some other *Aedes* and *Haemagogus*
Malaria	Primarily *Anopheles* mosquitoes
Chagas Disease	(Bugs from the genus *Triatoma)*
Rift Valley Fever	Mosquitoes from the genus *Aedes*

5) Diseases that may be present in Vermont or may spread to Vermont in the future but whose link with the climate changes expected in Vermont is tenuous	
Disease	**Primary mode of transmission**
Bartonellosis	Animal-borne
Rabies	Animal-borne
Hanta Virus	Animal-borne
Leptospiriosis	Animal-borne
Plague	Vector-borne / Animal-borne (by fleas and infected mammals, different transmission pathways)
Valley Fever (coccidiodomycosis)	Environmental
Anthrax	Environmental
Q fever	Environmental

Details of the categorization of these diseases are included in the sections below.

4.4.1 Mosquito-borne diseases

West Nile Virus

West Nile virus (WNV) is an arthropod-borne virus (arbovirus), most commonly spread by the bite of infected mosquitoes (CDC 2015a). Rarely, transmission has been associated with contact with the blood or tissue of other infected animals (WHO 2011). About one in five people infected with the virus develop fever, often accompanied by headache, body aches, joint pains, vomiting, diarrhea or rash. Less than 1% of infected people, however, develop dangerous neurologic illness such as encephalitis (inflammation of the brain) or meningitis (inflammation of the membrane around the brain and spinal cord). About 10% of these neuroinvasive cases are fatal (CDC 2015a). Unfortunately, no vaccine or specific anti-viral therapies are known, though some level of symptom management is possible through the administration of intravenous fluids, pain medication and nursing care (CDC 2015a).

WNV primarily cycles between mosquitoes and birds (CDC 2015a). To date, WNV has been detected in over 50 species of mosquito (CDC 2015a). Mosquitoes of the genus *Culex* play a particularly important role in WNV transmission in North America (VDH 2015). The species *Culex pipiens* and *Culex restuans*, which are particularly important in the transmission of WNV (Andreadis, Anderson, and Vossbrinck 2001), are common in Vermont. In total, there are 19 competent vectors already present in Vermont, including species from the genera *Aedes*, *Anopheles*, *Coquillettidia*, *Culiseta*, *Culex*, *Ochleratus*, *Psorphora* and *Uranotaeni*a.

WNV was first isolated in Uganda in 1937 and became established in North America after an outbreak in the New York metropolitan area in 1999. Vermont recorded its first human case of WNV in 2002, and by

2012, had recorded 9 cases (VDH 2015). Confirmed human cases over the 2003 to 2014 period are plotted in Figure 25, along with the percent of tested mosquito pools testing positive for the virus. Mosquito pools are sampling groupings of up to 50 mosquitoes of the same species, trapped at one site on one night. Many pools are tested in a given year, and the amount depends on factors such as the number of mosquitoes trapped; in 2014, there were over three thousand pools tested for the virus. As the figure shows, the percent of pools that test positive for WNV is not necessarily a good indicator of how many human cases will develop.

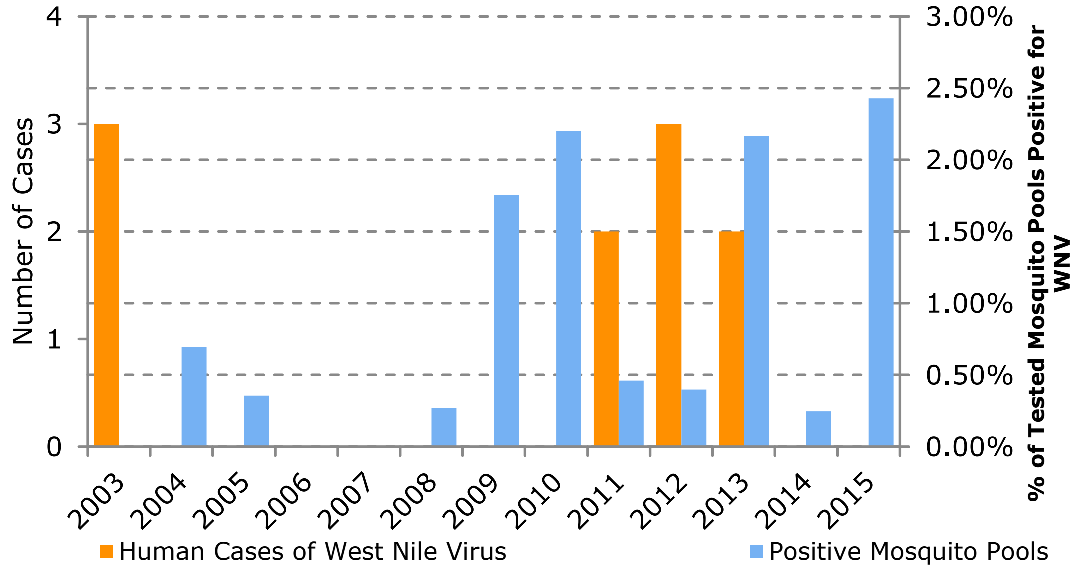


Figure 25: Human cases and mosquito pools testing positive for WNV in Vermont, 2003-2015 (data from VDH 2015)

The abundance of the above vectors appears to be sensitive to climate, specifically to temperature and moisture. Gong et al. have studied and modeled the dynamics of *Culex pipiens* and *Culex restuans* in New York State (Gong et al. 2010). The developmental rate of these mosquitoes from hatching to adulthood is strongly linked to temperature. For example, *Culex restuans'* development time drops from about 52 days at 50°F to 6 days at 93°F, though beyond that temperature, survival dwindles rapidly (Gong et al. 2010). Increases in moisture and rainfall increase mosquito flight and host-seeking activity and create a more favorable habitat for egg-laying (Gong et al. 2010). The Northeast Regional Climate Center has developed an online application that uses climate-driven models to forecast the abundance of WNV vectors in the Northeast (NRCC 2013). The three climate parameters used are:

1) growing degree days (GDD)[2] since March 15th: an accumulation of 230 degree days signals the start of mosquito hatching and development for that season;
2) moisture: when precipitation exceeds evaporation, mosquito populations are usually higher;
3) frost: temperatures below 32°F decrease mosquito activity; temperatures below 28°F generally end mosquito activity for the season.

With both temperature and precipitation expected to increase in Vermont, it appears likely that WNV mosquito vector activity will increase and that their total period of activity will lengthen. However, there are non-climate constraints on these changes. For instance, the lifecycle of *Culex pipiens* and *Culex restuans* is partially modulated by seasonal day length: the effect of shortening days begins to impact the activity of these mosquitoes as early as August (Gong et al. 2010). A further consideration is the effect that the changing climate might specifically have on urban mosquitoes, which are most likely to interact with humans. For example, *Culex pipiens*, when developing in the drainage systems of built-up areas, tend to thrive under dry spring conditions while heavy rainfall can wash away their eggs (Epstein 2001). Finally, depending on their timing and severity, extreme heat events could suppress summer mosquito populations (Morin and Comrie 2010). However, given Vermont's rural and temperate character, the effect of warming temperatures, increasing moisture, and later fall frosts are likely to predominate and create a more favorable environment for West Nile vector proliferation.

Eastern Equine Encephalitis

Eastern equine encephalitis (EEE) is a rare but serious viral disease that is transmitted to humans by the bite of infected mosquitoes (CDC 2010a).

While most people infected with the EEE virus do not develop symptoms, infection can lead to a systemic form of the disease involving chills, fever, malaise, arthralgia, and myalgia. This form of disease usually resolves within 1 to 2 weeks (CDC 2010a). In more serious cases, infection with the virus can also lead to encephalitis (swelling of the brain). It is this form of infection, when encephalitis develops, that is commonly referred to as EEE, or neuroinvasive EEE. About a third of these neuroinvasive EEE cases die from the disease. Death usually occurs 2 to 10 days after symptoms start, but can occur much later. Many patients who do survive do so with disabling and progressive mental and physical consequences, ranging from brain dysfunction to severe intellectual impairment, personality disorders, seizures, paralysis, and cranial nerve dysfunction. No vaccines or treatments for EEE, other than symptom management, are currently available (CDC 2010a).

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[2] Growing degree days (GDD) are a tool used to measure heat accumululation, which are typically used for gardening and farming, but also may be used for ecological and other purposes. Growing degree days are defined as the sum of growing degrees for all days within a specific time period, where:

$$Growing\ Degrees = Average\ Temperature - 50°F$$

If the average temperature is less than the base temperature of 50ºF, then the growing degrees for that day are defined as zero.

No human vaccine against EEE infection or specific antiviral treatment for clinical EEE infections is available. Patients with suspected EEE should be evaluated by a healthcare provider, appropriate serologic and other diagnostic tests ordered, and supportive treatment provided.

The EEE virus primarily cycles between the mosquito *Culiseta melanura* and birds in swamps and wetlands (CDC 2010a). *Culiseta melanura* can but rarely do feed on humans. However, bridge vector species from the *Aedes*, *Coquilletttidia*, *Culiseta*, *Culex* and *Ochleratus* genera can transmit the virus from infected birds to mammals, including humans. Figure 26 shows this cycle.

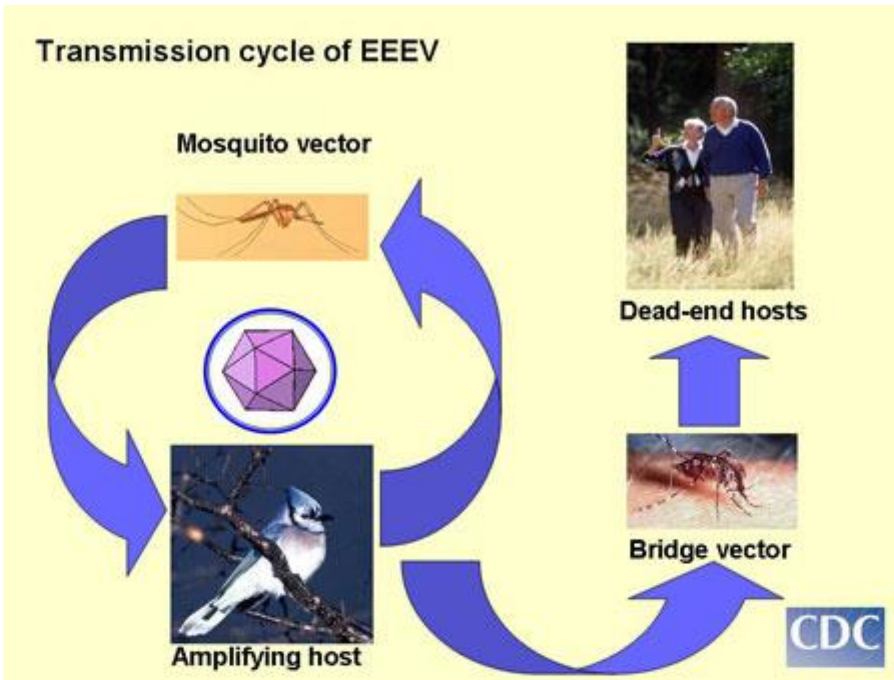

Figure 26 - Diagram of EEE transmission between mosquitoes, birds, and humans (CDC 2010a)

Only about 8 confirmed human cases of neuroinvasive EEE occur in the United States each year (CDC 2015b). However, more people than this may contract the virus and not develop severe symptoms. Unfortunately, despite its low incidence, the disease brought tragedy to Vermont in 2012, with the state's first two recorded human cases of EEE, both of which were fatal. This followed the first recorded animal cases in the state during an outbreak in a flock of emus in 2011. Sero-surveys of deer and moose detected that the EEE virus has been present in Vermont as early as 2010. These events have led to the development of a statewide mosquito testing system. In the summer of 2013, mosquitos tested positive for EEE virus in Addison County, leading to targeted aerial insecticide application.

Most EEE cases occur in the Atlantic and Gulf Coast states, with Florida accounting for 25% of cases over the period of 1964-2010 (CDC 2015b). Figure 27 shows a map of neuroinvasive EEE case distribution over that time period.

While the highest numbers of cases have occurred in the south, geographic distribution of EEE has shifted northwards during this time (Armstrong and Andreadis 2013). Over 2000-2004, Florida still had the highest average number of cases per year, at 1.4, but it was followed by Michigan, at 1.2 cases per year. Massachusetts recorded its first case in 1974 and by 2010, had 37 cases on record, with close to half of them occurring in the 2000s. Figure 28 compares counts of EEE cases in Florida and in the New England States, over the period 1964 to 2010. While it is difficult to draw trends with certainty based on such low and variable case numbers, annual cases counts in Florida have remained fairly stable within the 0 to 6 cases per year envelope, while case counts in New England have increased.

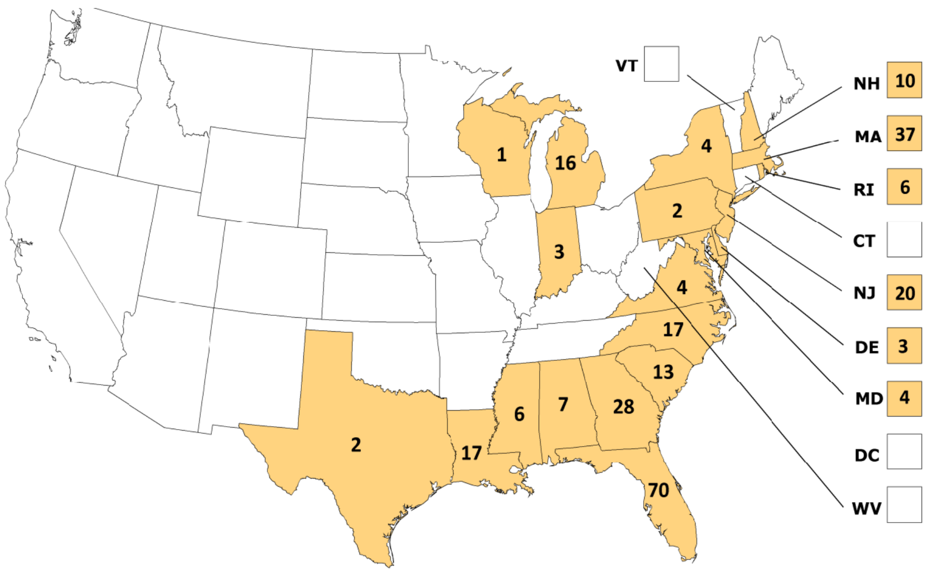

Figure 27: Geographic distribution of neuroinvasive EEE cases reported by state, 1964-2010 (adapted from CDC 2010a) Vermont cases occurred in 2012 and are not included in the map. *Note:* 1964-2010 maps are currently unavailable from CDC. Updated maps from CDC website include cases from 2003 onwards.

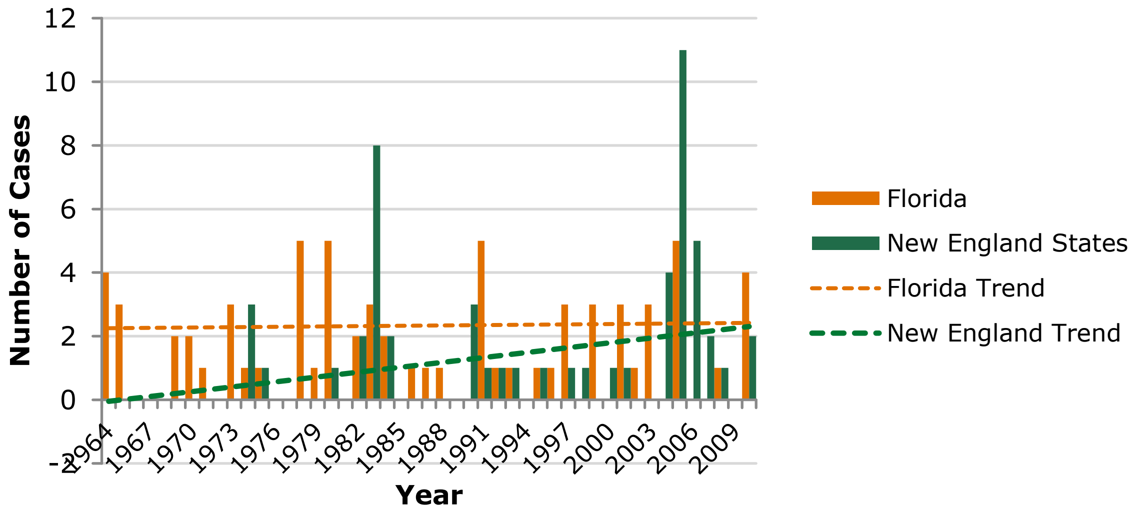

Figure 28: Recorded human cases of neuroinvasive EEE in Florida and the New England states, 1964-2010 (data from CDC 2010a)

Given the gradual increase in EEE cases in the northern reaches of New England, the possibility of a relationship between the disease and the changing climate should be considered. Mild winters and warm summer temperatures are linked to increased incidence of EEE (Armstrong and Andreadis 2013). Specifically, mild winters with insulating snow cover appear to create conditions favorable to overwintering of the EEE virus (MDPH 2012). Warm summer temperatures in turn appear to accelerate the mosquito reproductive and developmental cycles and shorten the interval between mosquito infection and the point at which the mosquito becomes capable of transmitting the infection (MDPH 2012). Furthermore, the projected lengthening of the mosquito season may increase the chances of human exposure (Armstrong and Andreadis 2013). Heavy precipitation, particularly in the preceding fall and spring, also appear to factors affecting the risk of EEE transmission (MDPH 2012). With rainfall projected to increase in both the fall and winter, the risk for EEE in Vermont may increase.

Saint Louis Encephalitis

Saint Louis encephalitis (SLE) is a viral disease transmitted to humans primarily by the bite of infected mosquitoes of the genus *Culex* (CDC 2010b). Most infected persons do not show symptoms, but some develop fever, headache, nausea, vomiting and fatigue. In some cases, particularly among older adults, a severe neuroinvasive form of the disease can develop, leading to encephalitis (brain inflammation). This severe form occasionally results in long-term disability or death (CDC 2010b). There is no treatment for the disease itself, only for its symptoms.

Transmission occurs through a mosquito-bird-mosquito cycle, with wild birds serving as the primary host and reservoirs of the virus. Sparrows, pigeons, blue jays and robins are frequent hosts that are also commonly found in urban and suburban areas, thus facilitating transmission to humans (CDC 2010b). Cases typically occur in the summer and fall in temperate areas of the U.S., but occur year-round in warmer areas. The most common vectors in the eastern US are *Culex pipiens* and *Culex quinquefasciatus* (CDC 2010b). *Culex pipiens* is already present in Vermont, as are four other less common vectors of the disease (VT AAFM 2013).Vermont does not to date have any recorded cases of neuroinvasive Saint Louis encephalitis.

Figure 29 shows SLE case counts by state over the last five decades. For reasons not fully understood, the disease is more common in southern and central states There was a major outbreak of the disease, centered on the Ohio-Mississippi River Basin, in 1975 (CDC 2010b). Eight of New York's 10 cases occurred in that year, and another of its cases occurred in 1978; after a long lull in cases, New York recorded another case in 2003. New Hampshire recorded its first case in 2006. There could potentially be a climate contribution to the northern spread of the disease, though the disease has been occurring in fairly temperate zones for some time.

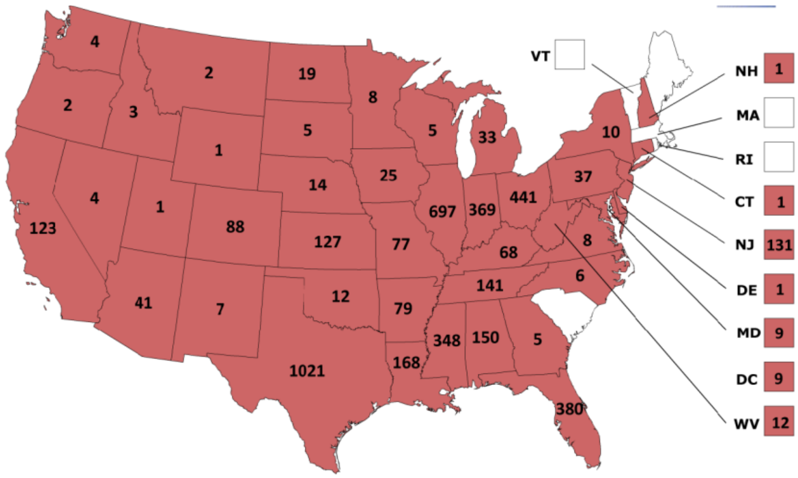

Figure 29: St. Louis Encephalitis Virus Neuroinvasive Disease Cases, 1964-2010 (adapted from CDC 2010b)

Western Equine Encephalitis

Western equine encephalitis (WEE) is a viral disease transmitted to humans primarily by the bite of infected mosquitoes of the genus *Culex* (CDC 2010, Reisen et al. 2010). Persons infected with the virus may experience a range of symptoms, from mild flu-like illness to severe inflammation of the brain, which in some cases and result in coma or death (CDC 2010c). There is no treatment for the disease other than control of symptoms (CDC 2010c). The disease's cycle, particular how it overwinters, is still poorly understood (CDC 2010c). Figure 30 shows WEE case counts by state. The disease is largely confined to the region west of the Mississippi. It is not immediately clear that the changing climate would trigger an eastward spread of the disease. However, *Culex* mosquitoes that act as competent vectors of the disease are present in Vermont (VT AAFM 2013). The changing climate may create a more favorable environment and longer period of activity for those mosquitoes, facilitating transmission of the disease in the eastern parts of the country.

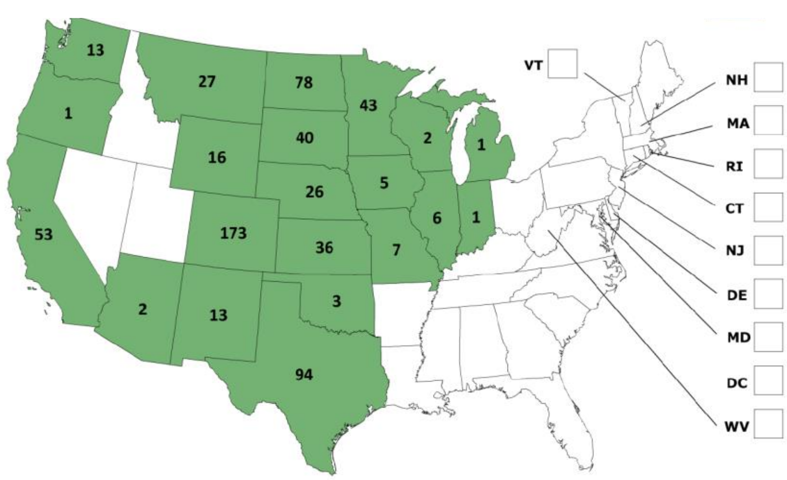

Figure 30: Western Equine Encephalitis Virus neuroinvasive disease cases, 1964 to 2010 (adapted from CDC 2010c)

La Crosse Encephalitis

La Crosse encephalitis virus is transmitted to humans primarily by the *Aedes triseriatus* mosquito, but also can be transmitted by other species in the genera *Aedes* and *Ochlerotatus* (CDC 2009a). The virus is maintained in a cycle between the mosquito and small vertebrate hosts, most often chipmunks and squirrels, in deciduous forests (CDC 2009). While most people infected with the virus do not develop symptoms, some infections do result in fever, headache, nausea, vomiting and tiredness (CDC 2009a). In some cases, a neuroinvasive form of the disease develops which can result in encephalitis (inflammation of the brain) and can lead to seizures, coma, paralysis and rarely long term disability or death (CDC 2009). Severe forms of the virus are most common among children aged 16 or younger (CDC 2009a). There is no treatment for La Crosse encephalitis other than management of symptoms (CDC 2009a). There are between 80 and 100 reported cases of neuroinvasive disease every year in the United States. Figure 31 shows that the distribution of cases over the 1964-2010 period is weighted towards the upper Midwestern and mid-Atlantic states. Northern New England has yet to report any cases, though New York has had 58. *Aedes triseriatus* as well as *Aedes cinereus* mosquitoes, which are competent La Crosse encephalitis virus vectors, are present in Vermont (VT AAFM 2013). So, La Crosse encephalitis could emerge in Vermont, with the underlying possibility that it is already present but undetected. It is unclear whether the changing climate would significantly affect the likelihood of disease spread to Vermont. However, an extended mosquito season and an environment favorable to mosquito proliferation could make transmission to humans more likely if the disease does make its way to Vermont.

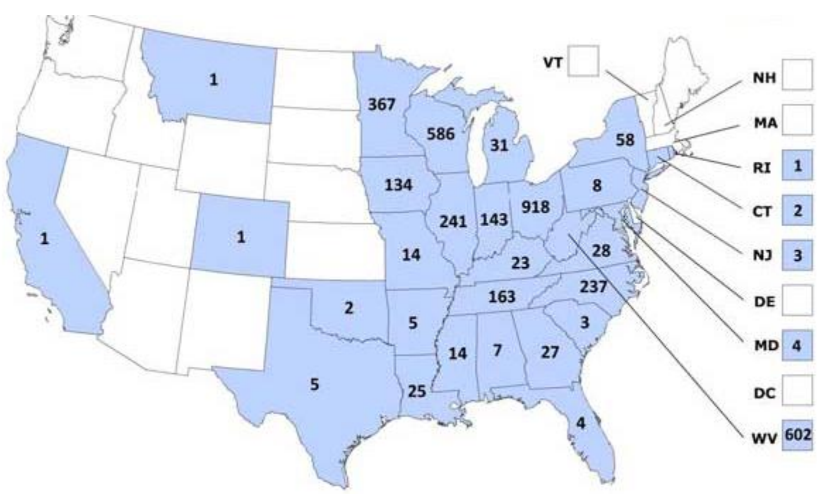

Figure 31: Cases of neuroinvasive La Crosse encephalitis by state, 1964 to 2010 (adapted from CDC 2009a)

Dengue

Dengue is a leading cause of illness and death in the tropics and subtropics, with as many as 400 million people infected globally every year (CDC 2015c). There is currently no vaccine for the four strains of dengue virus, which makes it a disease of particular public health importance, given the large number of cases that occur globally each year. Dengue is characterized by a high fever usually accompanied by other symptoms, including severe headache, eye pain, joint pain, muscle or bone pain, rash, mild bleeding and low white cell count (CDC 2015c). In some cases, infected individuals can develop dengue hemorrhagic fever, a more severe form of the disease. This causes internal bleeding which can in turn lead to shock and even death (CDC 2015c).

Dengue is transmitted primarily from human to human via the bite of infected mosquitoes *Aedes aegypti* and *Aedes albopictus*, which are also the vectors of the Yellow fever and chikungunya viruses (CDC 2015c). Both of these mosquitoes persist in more southern portions of the United States, but are not currently in Vermont (Rochlin et al. 2013). The vast majority of dengue cases in the continental United States remain those acquired abroad, however though there was a local outbreak in New Mexico in 2005, and local transmission in Florida in 2009 and 2010 (CDC 2010d). *Aedes aegypti and Aedes albopictus* are sensitive to climate, with their abundance correlating with increasing temperature and humidity (CDC 2012a). However, the number of Dengue cases does not necessarily correlate as well with mosquito abundance and is still poorly understood (CDC 2015c). Researchers in Texas found that factors such as housing quality, the use of air-conditioning and other lifestyle factors were associated with fewer dengue cases during a 1999 outbreak along the border of Texas and Mexico (Reiter et al. 2003).

Vermont does not currently have documented populations of either *Aedes aegypti* or *Aedes albopictus* (Rochlin et al. 2013). As the climate changes however, the environment suitable for these mosquitoes may expand northwards (Rochlin et al. 2013). For instance, the current climate-based northern boundary of *Aedes albopictus'* range in the Northeast is in New Jersey and Long Island (Rochlin et al. 2013). This boundary is set by a balance of cold winter temperatures that destroy mosquito eggs on the one hand and winter snowfall, which can help protect eggs from the cold, on the other (Rochlin et al. 2013). The impact of warming winters and increasing winter precipitation on the range of *Aedes albopictus'* have been modeled using GCM output. Figure 32 is a map of the projected range shift. Under the A2 scenario, by 2080 pockets of southern Vermont may become suitable to the mosquito's establishment, while under the B2 scenario, the range spreads into Massachusetts and New Hampshire, but does not Vermont (Rochlin et al. 2013). The other dengue vector, *Aedes aegypti* is most common in the southernmost portions of the eastern US, but has been implicated in historic outbreaks of yellow fever as far north New York, Philadelphia and Boston in the 1690's to 1820's (Eisen and Moore 2013). Such northerly historic outbreaks highlight the complexities of vector-borne disease dynamics and suggests that other factors in the built and natural environments aside from climate may also be limiting factors in the northern spread of these mosquito species (Eisen and Moore 2013). Even with the uncertainties of climate modeling aside, our limited understanding of the effect of climate on *Aedes* populations across various land-uses and ecological contexts, as well as of disease spread as affected by factors other than vector dynamics, make it difficult to assert that dengue will spread to Vermont in the future. It does appear plausible that the limits on vector spread currently imposed by climate may be altered – whether these alterations will be successfully exploited by the vectors or the disease is unclear.

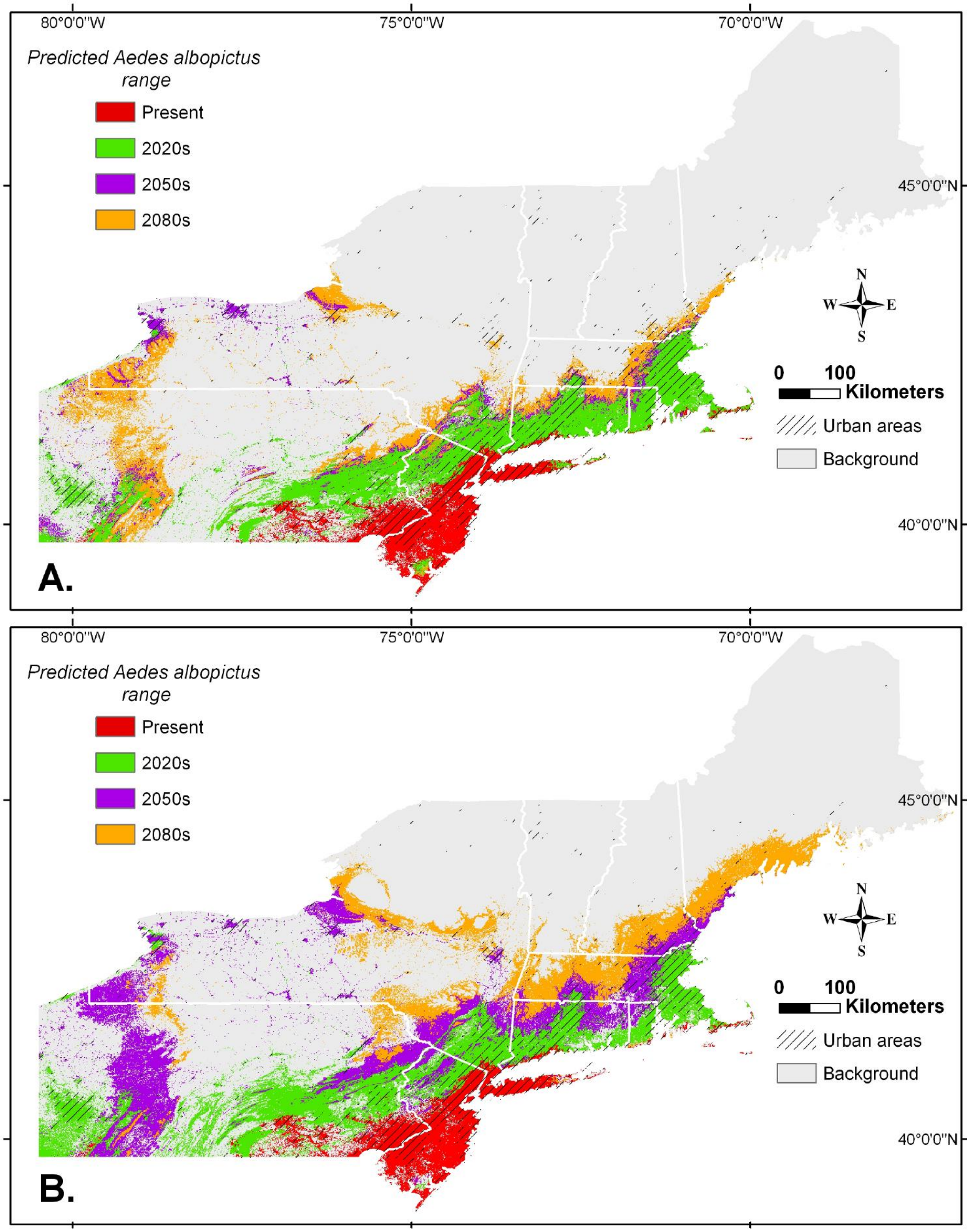

Figure 32: Modeled range expansion of Dengue vector *Aedes albopictus* in the Northeast. A is under the B2 scenario, B is under the A2 scenario. (Adapted from Rochlin et al. 2013)

Chikungunya
Chikungunya fever virus infection is most often characterized by fever, headache, fatigue, nausea, vomiting, muscle pain, rash, and joint pain (CDC 2015d). Joint pain can sometimes persist for several months. The disease is generally not fatal, and acute symptoms typically resolve within 7-10 days (CDC 2015d). Chikungunya shares the same vectors as dengue, *Aedes aegypti*, *Aedes albopictus*, and is often misdiagnosed as dengue (and vice-versa) due to its similar set of symptoms (CDC 2015d). Both species of mosquito are already present in the United States (Rochlin et al. 2013; Eisen and Moore 2013). Like dengue, chikungunya is primarily transmitted between humans via mosquitoes, although strains also circulate among non-human primates (CDC 2015d, Diallo et al. 2012). Like dengue, there is no apparent obstacle for chikungunya to spread to the United States in the future, given increasing temperatures. The disease has already spread to the Caribbean (CDC 2015d). As seen in the dengue section, the habitat range of *Aedes albopictus* may extend to southern Vermont by the end of the century under the A2 scenario (Rochlin et al. 2013; Eisen and Moore 2013). However, it is difficult to extrapolate from such a shift whether chikungunya itself will become established in the state over a similar timeframe, though such a development appears plausible.

Yellow Fever
Yellow fever virus is spread by mosquitoes of the genera *Aedes* and *Haemagogus* (CDC 2015e). The species *Aedes aegypti* is a particularly common vector (CDC 2015e). The disease is found in tropical and subtropical areas of South America and Africa (CDC 2015e). Panama is the northernmost limit of the South American endemic zone (CDC 2015e). This limit is most likely largely determined by the fact that the virus is best maintained in non-human primate populations (e.g. monkeys) (CDC 2015e). The disease can however jump from its primate-driven jungle and savannah cycles into an urban cycle, where it is exclusively transmitted between humans (CDC 2015e).

While most people infected with the Yellow fever virus never develop symptoms, those that do experience fever, chills, severe headache, back pain, general body aches, nausea, and vomiting, fatigue, and weakness. About 15% of cases go on to develop a severe form of the disease which may involve high fever, jaundice, bleeding and potentially shock and multiple organ failure (CDC 2015e). Unlike many of the diseases listed in this document, a vaccine exists for Yellow fever virus (CDC 2015e).

As seen in the dengue section, *Aedes aegypti* is present in the southeastern United States, yet no known Yellow Fever transmission occurs domestically. There were historic outbreaks of Yellow fever in New York, Philadelphia and Boston in the 1690's to 1820's, though the disease did not become endemic following these outbreaks (Eisen and Moore 2013). Improved urban sanitation and a decreasing reliance on water storage containers have probably played a role in ensuring that no such outbreaks have occurred in North America since the 1820s. The potential habitat of *Aedes aegypti* may spread to northward with the warming climate (see Dengue section). However, even if *Aedes aegypti* were to successfully exploit warmer temperatures, it does not seem likely that this would lead to Yellow fever outbreaks in the region, given the existence of an effective vaccine, and the lack of primate populations needed for the disease to become endemic outside of densely populated areas.

Malaria
Malaria is a serious, sometimes fatal, but treatable parasitic disease that is transmitted by mosquitoes of the genus *Anopheles* (CDC 2015f). The four primary species of malaria parasites that affect humans

(*Plasmodium falciparum, P. vivax, P. knowlesi,* and *P. malariae)* do not exist within animal reservoirs, but rather cycle almost exclusively in humans (CDC 2015f). About 1,500 cases of malaria are reported in the United States annually (CDC 2015f). The majority of these cases are thought to be acquired overseas, with the disease having been eliminated in the continental United States in the 1950s (CDC 2015f). Before this, *P. vivax* existed endemically within the United States. However, there have been 63 outbreaks of locally transmitted malaria between 1957 and 2011 (CDC 2015f). In these outbreaks, local mosquitoes become infected by biting individuals that were infected in endemic overseas locations and then transmit the disease to other people (CDC 2015f).

When malaria was prevalent in the United States, it was most often carried by three species of *Anopheles,* namely *An. quadrimaculatus* in the east, *An. freeborni* in the west and *An. albimanus* in the Caribbean, though other species of *Anopheles* contributed as well (CDC 2015f). While mosquito control through widespread pesticide usage was part of the initial malaria eradication strategy in the United States, the elimination of malaria has been maintained by rapidly treating human cases, eliminating the ability for *Anopheles* mosquitoes to bite infected individuals and transmit the disease to others. The parasite cannot reproduce in other animal hosts, with the exception of some species of primate (CDC 2015f), so rapid treatment of human cases is essential to preventing outbreaks in the United States. The *Anopheles* malaria vectors themselves continue to proliferate in the United States today. In Vermont, two competent malaria vectors, *An. quadrimaculatus* and *An. walkeri* are already present (VT AAFM 2013). While climate change might support more favorable conditions for these vectors, any reemergence of endemic malaria in the United States and Vermont would most likely be due to a failure of control measures (ie. not rapidly treating human cases).

Rift Valley Fever

The Rift Valley fever virus primarily affects livestock including sheep and cattle (WHO 2010). The potentially deadly disease can spread to humans through contact with the blood of infected animals or through the bite of mosquitoes that have previously bitten infected animals (WHO 2010). Its most common vectors are mosquitoes of the genus *Aedes* (WHO 2010). Several *Aedes* species that are competent vectors are already present in Vermont (VT AAFM 2013). If Rift Valley Fever were to spread to Vermont, it could potentially become established in local livestock and transmitted by local *Aedes* varieties. However, all documented cases of Rift Valley Fever to date have occurred in Africa and, most recently, in the Arabian Peninsula (WHO 2010). Though poorly understood, the rate of spread outside of that region appears to be very slow, so Rift Valley Fever is not a priority concern for Vermont among diseases that may be affected by climate change.

Jamestown Canyon Virus

Jamestown Canyon virus is widely distributed across temperate North America (Mayo et al. 2001). It generally causes mild fever and in rare cases meningitis or encephalitis. It is not known how many cases there have been in Vermont or in the wider region, though blood studies however suggest that about 4% of Connecticut residents have been exposed to the virus (Mayo et al. 2001). The virus cycles primarily between deer and mosquitoes, with humans acting as incidental hosts of the disease. There are at least 11 competent mosquito vector species in Vermont, divided between the *Aedes, Anopheles,* and *Ochlerotatus* genera (VT AAFM 2013). A changing climate could result in proliferation and lengthened seasons of activity of some of these vectors, facilitating the transmission of the disease.

4.4.2 Tick-borne Diseases

Lyme disease

Lyme disease is caused by infection with the bacteria *Borrelia burgdorferi* (VDH 2014a). In the eastern United States, the infection is transmitted by the bite of *Ixodes scapularis* ticks, commonly known as black-legged ticks or deer ticks. Lyme disease is treatable with antibiotics. The symptoms of Lyme disease can vary because various body parts can be affected, including the skin, heart, nerves, or joints. Early symptoms usually start within 3 to 32 days after infection (mean 7 to 10 days) from a tick bite and can include fatigue, chills, fever, muscle and joint pain, headache, swollen lymph nodes and a characteristic bull's eye rash, usually near the bite, known as erythema migrans (Heyman 2008; VDH 2014a). If the disease is not recognized and treated in the early stages, it can spread to other parts of the body, in what is known as disseminated Lyme disease. Symptoms of disseminated Lyme disease can occur days to months after initial infection and can include numbness and pain in the arms and legs and paralysis of facial muscles, usually on one side of the face. In some cases, meningitis may occur, resulting in fever, stiff neck and severe headache. In rare cases, disseminated Lyme results in an abnormal heartbeat. Up to 60% of people who do not receive treatment develop bouts of arthritis, characterized by severe pain and swelling at the joints. A small number of cases develop chronic nervous system problems months to years after infection. These chronic nervous problems include shooting pains, numbness or tingling in the hands and feet and problems with concentration and short term memory.

The lifecycle of the black-legged tick comprises four successive stages, egg, larva, nymph, and adult. This lifecycle generally spans two years, but is dependent on climatic factors (CDC 2011). Progression to each successive life stage after hatching requires one blood meal from a single host (CDC 2011). The lifecycle is summarized in **Error! Reference source not found.**. Eggs hatch into larvae, which are initially uninfected. Larvae feed on mice and other small animals. If one of their hosts is infected with *Borrelia burgdorferi,* the larvae may become infected and then stay infected throughout their lifecycle (CDC 2011). After a larva takes a blood meal, it falls off of its host and over time molts into a nymph. A nymph also takes a single blood meal, often from bigger mammals such as deer or humans (CDC 2011). Nymphs are most common in the spring and summer. After taking their blood meal, nymphs drop from their hosts and develop into adults. Adults will take a final blood meal, during which they can transmit *B. burgdorferi* if they are carriers. Adult females then lay eggs, restarting the cycle. Because of this life cycle, only nymphs and adults can transmit *B. burgdorferi*. Nymphs are the most likely to transmit disease to humans because they are small (about the size of a poppy seed) and can stay attached for longer periods without being noticed.

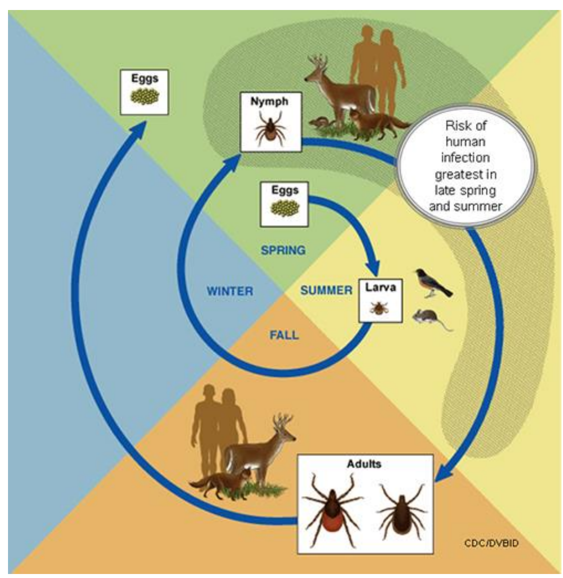

Figure 33: Lifecycle of the black-legged tick, Ixodes scapularis (CDC 2011)

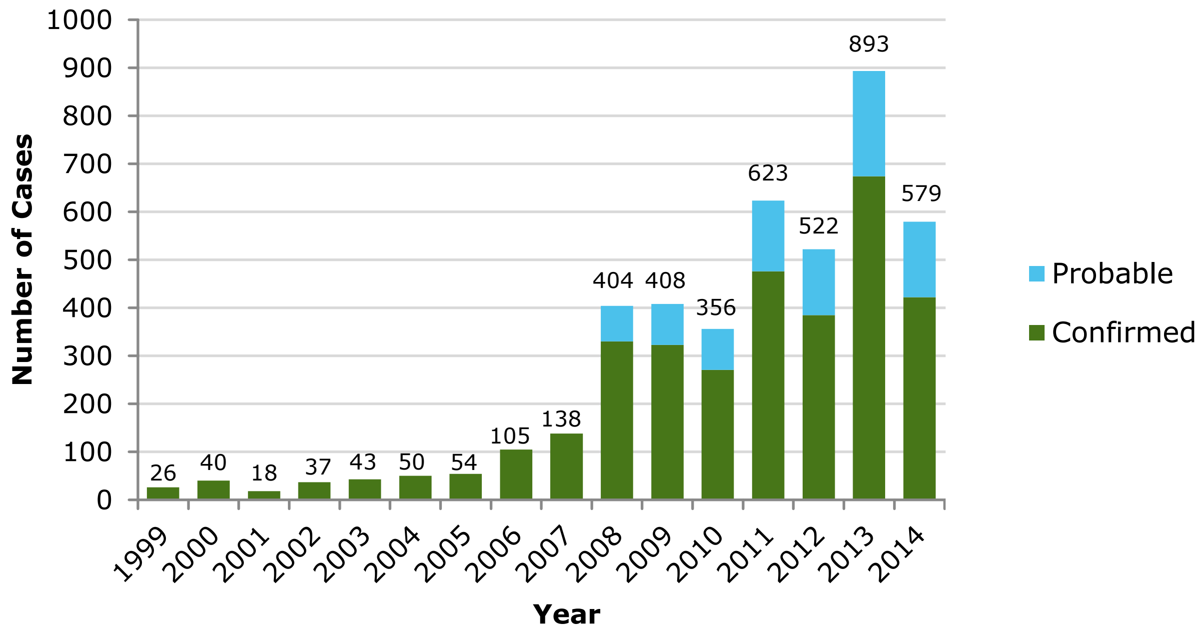

Figure 34: Cases of Lyme disease in Vermont, 1999 to 2014. Case counts from 2008 onwards include both confirmed and probable cases. Prior to 2008, probable cases were not reported. Confirmed cases represent 75% of the total for the years 2008 to 2014. Cases include both those acquired in Vermont (majority) and those acquired out of state.

The number of cases of Lyme disease reported in Vermont has increased dramatically over the last decade.

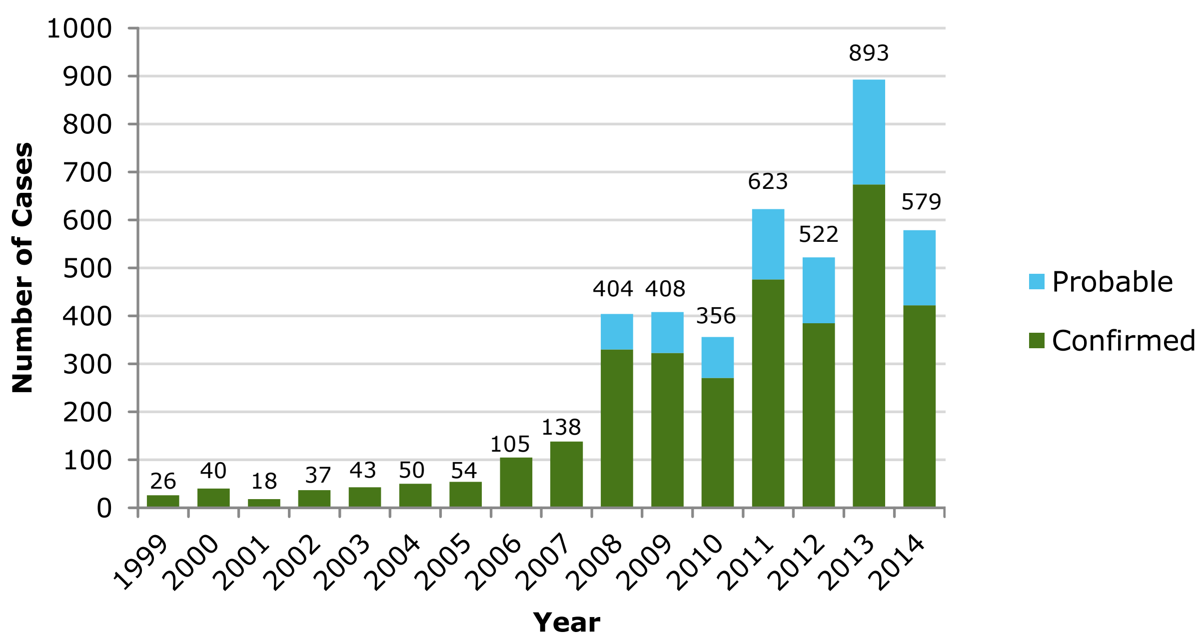

Figure 34 shows the number of reported cases over the years 1999 to 2014. Lyme disease was first identified in an outbreak in Lyme, Connecticut in the 1970s (NIAID 2012). However, the disease itself appears to have been described in Europe medical literature in the early 20th century (NIAID 2012). It is unclear when or how the pathogen made its way to North America: one genetic study of *B.burgdorfi* suggests that it may have already been present in pre-colonial times (Hoen et al. 2009). Figure 35 compares the distribution of Lyme disease cases in the United States in 2001 and in 2012. The majority of cases are concentrated in the Northeast and Midwest, and the range of cases appears to have expanded in this time.

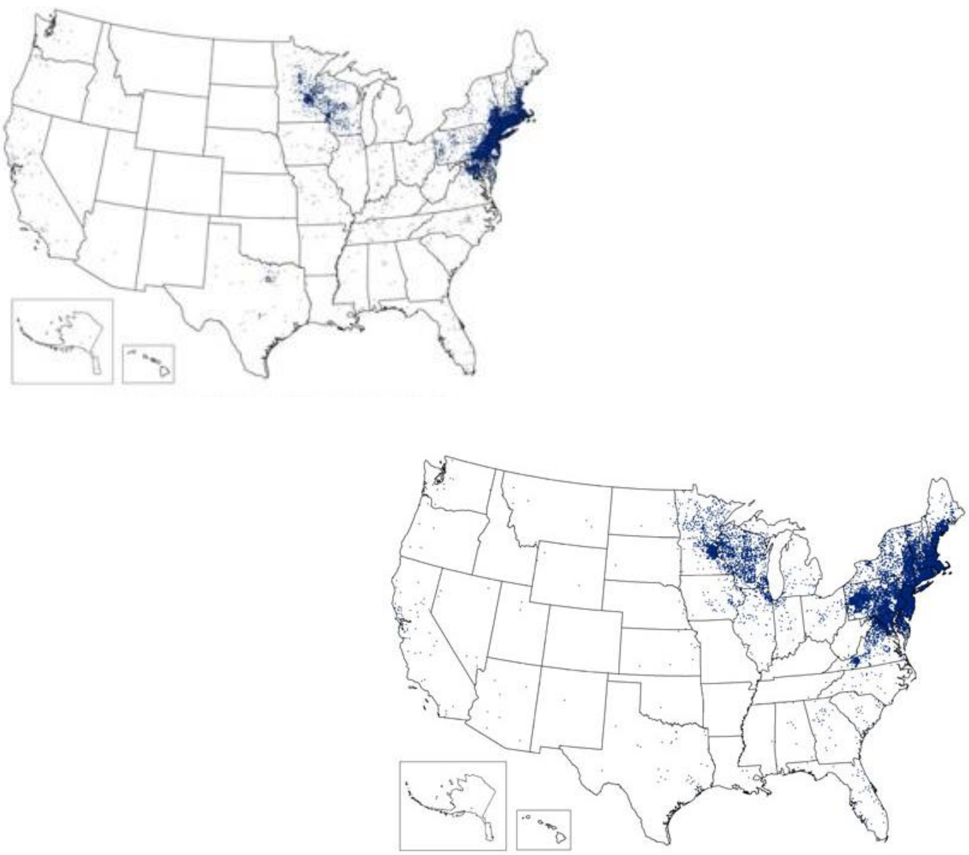

Figure 35: Cases of Lyme disease by county, 2001 (top) and 2012. (bottom). One dot placed at random in county of incidence per case. Note the multi-directional spread of Lyme disease from one epicenter in the Northeast and one in the Midwest (adapted from CDC 2015g).

Much uncertainty remains about what factors have caused the increase in incidence of Lyme disease in recent years. Some portion of the spread may be due to better detection and reporting of the disease by physicians. Another driver could be an increase in black-legged tick abundance, which has been reported anecdotally in Vermont. Although there have been active tick surveillance efforts in place since 2013, there are no corresponding long-term tick counts in Vermont to give an indication of whether tick populations have increased and by how much over the years that Lyme disease has increased. Another potential contributing factor in the surge of Lyme in the northeast is the region's reforestation and associated rise in white-tail deer population (Hoen et al. 2009). By the end of the 19th century, only about

30% of Vermont was forested while today, about 78% is forested (Adelman 2008). Such an increase in forest cover, while beneficial in many capacities, could provide a more suitable habitat for ticks and tick hosts, particularly white tailed deer and white-footed mice. Furthermore, there are indications that fragmented land uses, in which forested and residential areas mix, create higher risk. For instance, Brownstein *et al*. found an association with fragmented land use in Connecticut and higher tick densities and higher rates of tick infection, although they did not find higher human infection rates (Brownstein et al. 2005). Tran and Waller, on the other hand, found a positive association between fragmented land use and county-level human infection rates in thirteen states in the Northeast (Tran and Waller 2014).

Given the above possible contributors to the spread of Lyme disease, the contribution of climate change is difficult to assess. However, researchers continue to advance understanding of the effect on climate on the dynamics of ticks, intermediate hosts and pathogens. A recent modelling study of tick dynamics suggests that the basic reproductive number of *I. scapularis,* i.e. the number of offspring that each tick generates, may double in the Northeast from about 3.5 to about 7.1, by 2051-2069 under the A2 scenario (Ogden et al. 2014). When the model was applied to the 1971-2010 period, it appeared to be consistent with reported basic reproductive numbers (Ogden et al. 2014). The modelling effort supports the hypothesis that warming temperatures helped drive Lyme disease spread, along with reforestation, rising deer populations and other factors (Ogden et al. 2014). The projected increase in reproductive number carries three important implications:

1) Areas that are at present climatically unsuitable as deer tick habitat may become infested in the future;
2) In regions already suitable but not yet infested, the rate of invasion will be accelerated;
3) Tick abundance may increase in areas where the ticks are already present;
(Ogden et al. 2014)

Based on these findings, deer ticks in Vermont may become more abundant where they are already present, and may become more widely distribute, reaching areas with higher latitudes and elevations. A greater number and distribution of ticks could lead to greater disease transmission (Ogden et al. 2014).

In addition to an expansion of tick habitat and an increase in abundance, the tick period of activity is likely to increase. Deer ticks are not active when temperatures are below freezing (Ogden et al. 2008). With the warming climate, potential days of activity and by extension potential days of possible human exposure are expected to increase. However, the dynamics of Lyme disease transmission are extremely complex and dependent on multiple factors, many of which themselves are in turn affected by temperature (Ogden et al. 2008).

Anaplasmosis

Human granulitic anaplasmosis (also referred to as HGA, formerly as human granulocytic erlichiosis (HGE) [prior to a taxonomic reorganization of the organism in 2001], and also simply ‘anaplasmosis’) is a disease caused by infection with the bacterium, Anaplasma phagocytophilum. Among tick-borne diseases in Vermont, anaplasmosis incidence is second only to that of Lyme disease. Furthermore, the number of cases has been steadily increasing over the past five years (Figure 10). Anaplasmosis has been one of the CDC’s nationally notifiable conditions since 2008 (Code 11090, confirmed and probable).

Anaplasmosis is a disease caused by infection with the bacterium, *Anaplasma phagocytophilum*. It cycles naturally among small and large mammals via the bite of ticks in the Ixodes genus. In the eastern United States, the disease is spread by the bite of infected black-legged ticks (*Ixodes scapularis)*. This is the same tick that can transmit Lyme disease (VDH 2013a). Symptoms of anaplasmosis can be similar to those of the flu and may include headache, fever, chills, muscle aches and fatigue. Less commonly, people may experience abdominal pain, nausea, vomiting, diarrhea, joint aches, and a rash. Signs of illness typically appear 5 to 21 days following a tick bite and tend to last about 1 to 2 weeks. Most people experience mild illness and recover fully without persistent complications. However, people with weakened immune systems and those with underlying medical conditions may experience severe symptoms (VDH 2013a). When the severe form of the disease does develop, it can lead to breathing difficulties, hemorrhage, renal failure or neurological problems. About 1% of cases die as a result of these complications (CDC 2013b). Anaplasmosis is treatable with antibiotics (VDH 2013a).

In 2010, about 90% of cases nationally occur in the six states of New York, Connecticut, New Jersey, Rhode Island, Minnesota, and Wisconsin (CDC 2013b). Figure 36 shows the anaplasmosis incidence by state in 2010. This was the year that Vermont had its first 2 recorded cases of the disease (VDH 2013a).

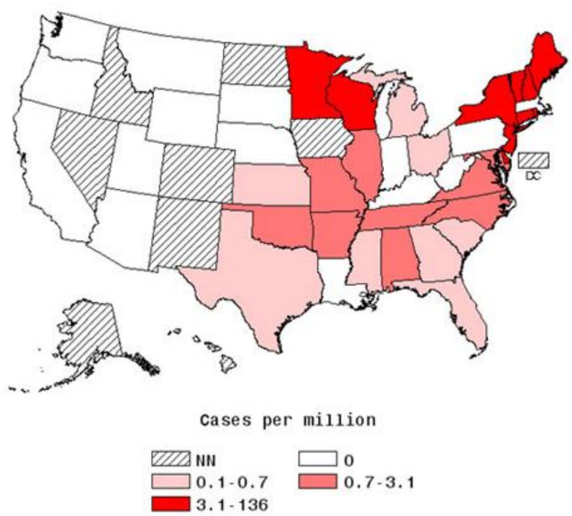

Figure 36: Anaplasmosis incidence 2010 (CDC 2013b)

The relationship between climate and the increasing incidence of anaplasmosis is not clear. The disease transmission cycle overlaps substantially with that of Lyme disease. Please see the Lyme disease section for a discussion of the relationship of climate with black-legged tick dynamics.

Babesiosis

Babesiosis is caused by the parasite Babesia microti, and is transmitted to humans by the black-legged tick (*I. scapularis*). It may also be transmitted between rodents by mouse ticks (*Ixodes muris*), which do not bite humans. Many people who are infected with *B. microti* do not experience any symptoms at all, while others may develop nonspecific symptoms including headache, fever, chills, and fatigue. Symptoms can appear from about one week to several months after infection. Because these parasites infect and destroy red blood cells, infection can lead to hemolytic anemia which can result in jaundice and dark urine. Babesiosis can be a potentially life-threatening illness for the elderly and people with weakened immune systems. People with chronic health conditions, such as liver, spleen or kidney dysfunction, are also at higher risk for developing a serious illness (VDH 2013c). Babesiosis can be effectively treated with antimicrobials (VDH 2013c).

As can be seen in Figure 37, the incidence of babesiosis has a similar pattern to that of both Lyme disease and anaplasmosis. Vermont had its first cases of babesiosis in 2012 (CDC 2014c). However, in other areas of the Northeast, including areas in Connecticut, Massachussetts, Rhode Island, southern New York, and New Jersey, it is endemic (VDH 2013c). The disease transmission cycle overlaps substantially with that of Lyme disease. Please see the Lyme disease section for a discussion of the relationship of climate with black-legged tick dynamics.

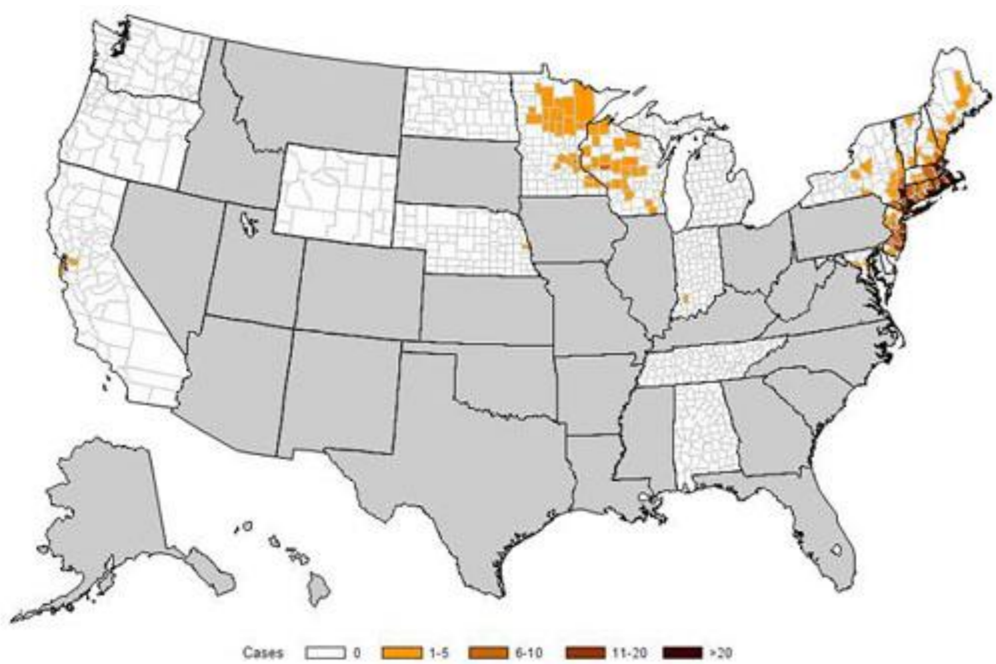

Figure 37: Babesiosis incidence 2012 (CDC 2014c)

Ehrlichiosis

Ehrlichiosis is a general name used to describe illnesses caused by infection with one of several species of *Ehrlichia* bacteria, most commonly *Erlichia chaffeensis,* the agent of human monocytic ehrlichiosis. The lone star tick, *Amblyomma americanum* tick, known by its common name due to its' singular distinctive spot, is the primary vector of *Ehrlichia chaffeensis* and *Erlichia ewingii* in the United States (VDH 2013d). Once inside the infected individual, the bacteria targets white blood cells, causing an infection that usually results in flu-like symptoms. Symptoms of ehrlichiosis usually appear one to two weeks after a bite from an infected tick. The most common symptoms are fever, headache, fatigue and muscle aches. A rash can occur in up to 25% of adults and 60% of children. Patients can also experience nausea, vomiting, diarrhea, joint pain and confusion. Infection usually produces a mild to moderately severe illness, and early treatment usually results in full recovery. Typically, symptoms of the disease last from one to two weeks. Occasionally complications occur, including respiratory problems, blood and kidney abnormalities, meningitis and other central nervous system problems. Ehrlichiosis can occasionally be a life-threatening disease with an estimated 1.8% of illnesses resulting in death (VDH 2013d). Ehrlichiosis is treated with antibiotics. Early treatment usually leads to a rapid recovery. Hospitalization is sometimes necessary for people with more severe illnesses (VDH 2013d).

Figure 38 shows an incidence map for ehrlichiosis, which largely corresponds with the territory of the lonestar tick (CDC 2010). Reports from the Vermont Tick Tracker and veterinarian tick submissions to the state, indicate that lone star ticks populations may currently exist in Vermont, albeit in small numbers, although they have not yet been found in active tick surveillance efforts (ie. systematic trapping efforts). Warming temperatures are likely to make Vermont have more favorable environments for lone star ticks to live in, and may facilitate the introduction of erlichiosis as an endemic disease in the state. Modeled simulations by Ludwig and others (2016) suggest that *A. americanum* tick populations could survive as far north as Montreal under current climatic conditions, indicating that areas of Vermont can also be suitable habitat for these ticks.

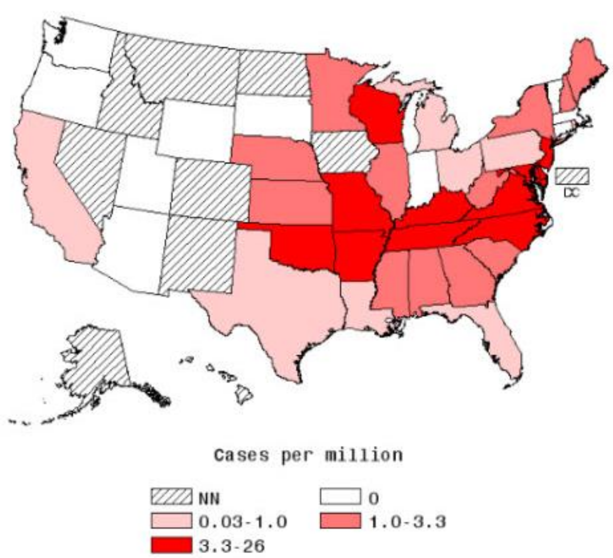

Figure 38: Incidence of Ehrlichiosis in 2010 (CDC 2013)

Powassan / Deer Tick Virus

Powassan (POW) virus causes a rare but serious disease and is transmitted through the bite of an infected tick, most often *Ixodes cookei*, commonly known as the groundhog tick or woodchuck tick. The virus was first identified in 1958 and named after Powassan, Ontario, the town of its discovery. POW virus is related to some mosquito-borne viruses, including West Nile virus (VDH 2013f). Most people who become infected with POW virus do not feel ill, but symptoms of the disease can be severe. Symptoms include fever, headache, vomiting, muscle weakness, drowsiness, confusion, loss of coordination, speech difficulties and memory loss. The virus can also infect the central nervous system and cause encephalitis (inflammation of the brain) or meningitis (inflammation of the membranes surrounding the brain and spinal cord). About 10% of POW virus infections result in death. Some patients who recover from the initial illness have continuing neurological problems (VDH 2013f). There is no specific treatment for

POW virus disease. Treatment consists of supportive care, rest and increased fluid intake to prevent dehydration (VDH 2013f).

In 1999, one Vermont resident was diagnosed with Powassan encephalitis. There have been no reports of POW virus disease in Vermont since then. Cases of POW virus disease have been reported from New York, Maine, and other northern states in the US, as well as the Canadian provinces of Ontario, Quebec and New Brunswick (VDH 2013f). Figure 39 shows the distribution of cases in the United States from 2002 to 2012.

Ixodes cookei is found east of the Rocky Mountains and from as far south as southern Texas to as far north as northeastern regions of United States and Canada. This tick feeds mostly on woodchucks and other medium-sized mammals but will bite people if given the opportunity (VDH 2013f).There is another type of POW virus that is likely spread by black-legged ticks (*Ixodes scapularis*). This type is sometimes called deer tick virus. It is not known how often this type of POW virus causes human illness, but a few cases have been reported in other states. Deer ticks are abundant in Vermont. Since the virus is already present north of Vermont, it does not seem likely that climate change would be driving a geographic expansion of the disease. However, climate could affect tick activity, reproduction, survival, and tick season length.

Figure 39: Distribution of cases of neuroinvasive Powassan virus, 2001 to 2012 (CDC 2013)

Rocky Mountain spotted fever

Rocky Mountain spotted fever (RMSF) is an illness caused by infection with the bacterium *Rickettsia rickettsii*. It is spread primarily by the bite of infected American dog ticks (*Dermacentor variabilis*). Symptoms of RMSF usually begin of 2-14 days after the bite of an infected tick. Early symptoms are similar to the flu although frequently more severe. These symptoms may include rash, headache, body aches and fatigue. More serious consequences such as damage to the lungs, heart and kidneys, may occur if the condition is left untreated (VDH 2013g).

RMSF has been reported from all areas of the country, but five states (North Carolina, Oklahoma, Arkansas, Tennessee, and Missouri) account for over 60% of cases. Figure 40 shows the case distribution of RMSF in the United States. There have been no illnesses reported in Vermont, although the American dog tick is established in Vermont (VDH 2013g).

The spread of RMSF into the northeast may be exacerbated by climate change, as temperatures rise and become more similar to those that currently exist in more southern states, where the disease is more common. However, other factors may affect the survival and reproduction of the American dog ticks that transmit the disease, so no strong predictions about the effect of climate change on RMSF in Vermont can be made at this time.

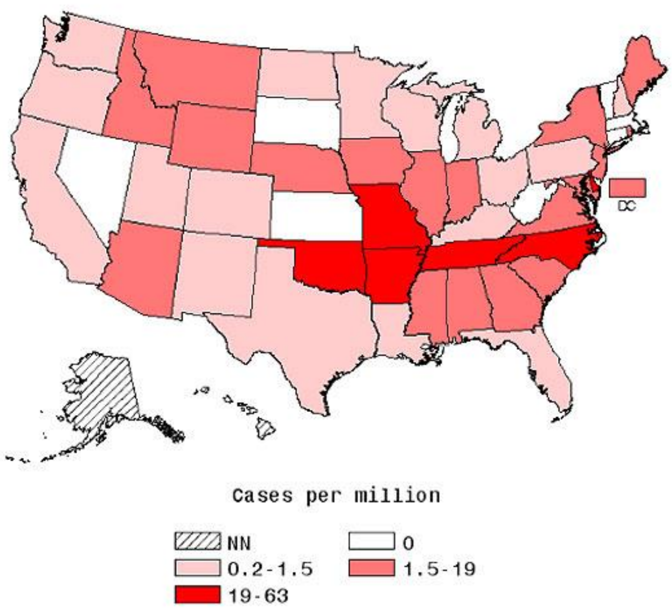

Figure 40: Incidence of Rocky Mountain Spotted Fever in 2010. While Vermont does not have any recorded cases, New York, New Hampshire and Maine have already had cases (CDC 2013c)

Tularemia

Tularemia, also known as rabbit fever or deerfly fever, is caused by infection with the bacterium *Francisella tularensis*. There are several ways that people can become infected with tularemia, including tick and deerfly bites, contact with infected animals, drinking contaminated water or breathing in contaminated dusts or aerosols. Tularemia is included in this section because while tick bites are not the only mode of transmission, they may be the most climate sensitive one. As with RMSF, the tick that carries the disease is the American dog tick (*Dermacentor variabilis*). The symptoms of tularemia vary depending upon the route of transmission though frequently they include sudden onset of fever, chills, headache, muscle aches, chest pain and coughing. Tularemia is treatable with antibiotics and most people recover completely (VDH 2013h).

Only one case of tularemia has been documented in Vermont since 2001 (VDH 2013h). Figure 41 shows the distribution of Tularemia cases in the United States, from 2003 - 2012. While there does appear to be a spread northwards of the disease, the extent to which climate change is responsible is not clear, particularly given that there was an outbreak in Vermont 1968, which was was attributed to people handling muskrats (Young et al. 1969). However, tick dynamics are climate sensitive and could be affected by climate, potentially altering the spread of tularemia. Nakazawa and others (2007) evaluated spatial patterns of tularemia in the United States as they related to climate change, and found that shifts in the distribution of cases from the 1960s to 1990s could be attributed to changes in climate, however northward shifts have been slight. There is not any good evidence yet that climate change will add any substantial risk for more tularemia cases in Vermont in the coming century.

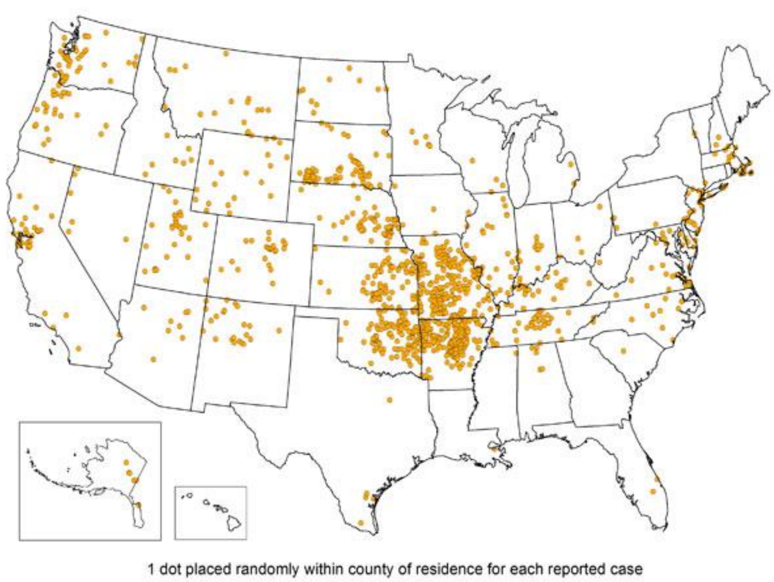

Figure 41: Distribution of Tularemia cases, 2003-2012 (CDC 2013d). While the disease has been reported in all states, except Hawaii, it is most common in the central United States.

3.4.3 Other Arthropod-borne Diseases

Chagas Disease

Chagas disease, or American trypanomomiasis, is transmitted by triatomine bugs (*Triatoma spp.)*. Chagas disease has an acute and chronic phase. The acute phase most often results in fairly mild fever and swelling around the bite. However, 20 to 30% of infected people enter a dangerous chronic phase that can lead to a dilated heart, dilated esophagus or colon and heart rhythm abnormalities that can cause sudden death (CDC 2013e). The disease is endemic in Central and South America and as far north as Mexico (CDC 2013e). As shown in Figure 42, triatomine bugs, or "kissing bugs", are already present in the

United States and have been reported as far north as Pennsylvania (CDC 2013e). Furthermore, an estimated 300,000 people in the United States already have chagas disease. However, the vast majority of these infections are thought to have originated outside of the country. This is because infection is not a simple process dependent on a single bite. Rather, it occurs when fecal material from the bug is rubbed into the bite wound, usually while the patient is sleeping (CDC 2013e). Thus a heavy infestation of a house with triatomine bugs is usually necessary for infection to occur. Triatomine bugs however primarily thrive in substandard housing and particularly in houses with thatched roofs (CDC 2013e). Housing in the United States is generally sealed well enough to prevent infestation by triatomines (CDC 2013e). Thus while the threat of triatomines spreading to Vermont with warming temperatures may be plausible, the spread of Chagas disease to the state appears unlikely.

Figure 42: Distribution of triatomine bugs in the United States (adapted from CDC 2013e)

Plague

Plague is a disease caused by the bacteria *Yersinia pestis.* There are three typical forms of plague caused by this bacteria, depending on the route and progress of infection: bubonic plague (infection centered in the lymph nodes), septicemic plague (disseminated infection in the blood), and pneumonic plague (infection in the lungs). Depending on the form, symptoms include fever, headache, chills weekness, abdominal pain, internal bleeding, and pneumonia, among others. Without prompt treatment with antibiotics, plague can cause serious illness and death (CDC 2015h). It is typically transmitted amongst rodent populations through the bite of fleas, which in turn occasionally will bite humans and other mammals. The oriental rat flea (*Xenospylla cheopis*) is the primary flea vector of the disease. However, humans can also contract the disease through direct contact with bodily tissues and fluids (ex. blood) of infected animals. Additionally, there can be direct transmission of plague from one mammal to another through aerosolized droplets (e.g. through coughing droplets) (CDC 2015h). About seven cases of plague occur in the United States every year, most frequently in the southwest, where plague exists endemically among ground squirrel populations. Figure 43 shows the distribution of cases since 1970. Studies have suggested that outbreaks in the southwestern United States are more likely to occur on cooler summers following wet winters (CDC 2015h). The nature of this climate relationship and its applicability to Vermont is currently insufficiently understood to be able to assess the impact of climate change on plague risk in Vermont (CDC 2015h)

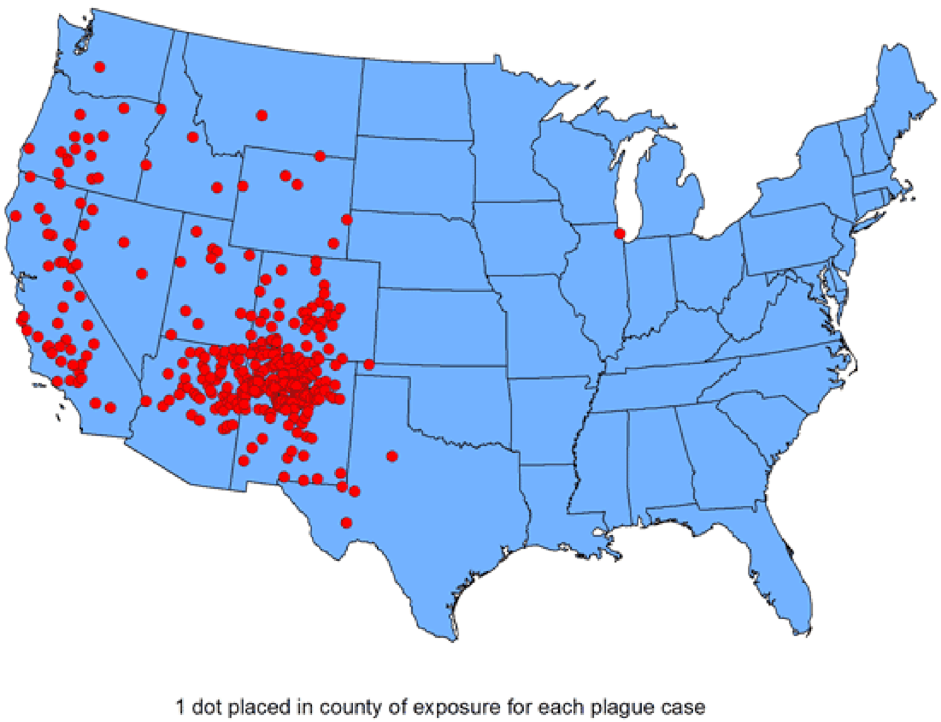

Figure 43: Reported cases of human plague in the United States, 1970-2012 (CDC 2015h)

3.3.4 Rodent and Other Animal-borne Diseases

Bartonellosis

Bartonella bacteria can cause several diseases, including cat scratch disease, trench fever and Carrion's disease (CDC 2012b). Cat scratch disease is transmitted to humans by scratches and bites from cats. Ticks can be carriers of the disease but it is not clear whether they can transmit the disease directly to humans (CDC 2012b). Trench fever is transmitted by body lice (CDC 2012b). Carrion's disease is transmitted by sand flies in Peru (CDC 2012b). The link between Vermont's anticipated changes in climate and these three diseases is not clear at this time.

Rabies

Rabies is a viral disease usually transmitted by the bite of a rabid animal. While a very serious and often fatal disease when contracted by humans and proper measures are not taken shortly after the bite, the evidence for a substantial change in disease dynamics of rabies in Vermont brought on by the changing climate is weak at this time.

Hantavirus

Infection with hantavirus can lead to hantavirus pulmonary syndrome which is frequently fatal. Hantavirus is transmitted to humans by contact with infected rodents or their urine (CDC 2014d). While most cases of hantavirus have occurred in the Southwest, cases have also occurred in New England, with one reported in Vermont (CDC 2014d). An outbreak in the Four Corners area in 1993 has been associated with a rapid increase in the mouse population, driven by heavy precipitation in the preceding spring (CDC 2014d). However, while a climate connection is plausible, it is not clear that the climate effects projected in Vermont would significantly increase the local mouse populations the way they did in the Southwest during its outbreak.

Leptospirosis

Infection with leptospirosis can lead to high fever, muscle aches, severe headache, chills, red eyes, and vomiting. The disease is treatable with antibiotics (CDC 2014e). It is spread through the urine of infected animals, including cattle, pigs, horses, dogs, rodents and wild animals (CDC 2014e). Infection with leptospirosis is rare in the United States, with 100 to 200 cases occurring annually (CDC 2014e). Spikes in incidence have been reported in Peru and Ecuador following heavy rainfall (CDC 2014e). Vermont had an outbreak in 2008, linked to recreational water and possibly associated with heavy summer rains (VDH 2008). With heavy rain projected to increase in Vermont, the incidence of leptospirosis may increase as well. However, it should be noted that the disease remains quite rare throughout the United States, including regions with much heavier rains and warmer temperatures than Vermont.

Q fever

Q fever is caused by the bacteria *Coxiella burnetii*. Its acute stage is characterized by high fever, as well as severe headache, general malaise, myalgia, chills, sweats, cough, nausea, vomiting, diarrhea, abdominal pain and chest pain (CDC 2015i). In less than 5% of cases, Q fever can develop into a chronic stage that can result in pneumonia, inflammation of the liver, inflammation of the heart and central nervous system complications (CDC 2015i). Cattle, sheep and goats are the primary reservoir for the disease. Transmission generally occurs by inhalation of barn dust contaminated by the urine and feces or dried placental and birth fluids of infected animals (CDC 2015i). Occasionally, drinking unpasteurized milk or tick bites can transmit the disease as well (CDC 2015i).

About 120 to 140 cases of Q fever have occurred every year between 2006 and 2010 (CDC 2015i). Q fever is most common in western and plains states where ranching is widespread (CDC 2015i). There were no recorded cases of Q fever in Vermont in 2010 (CDC 2015i). While plausible mechanisms for an increase in Q fever transmission risk with warming temperatures could be envisioned, there is weak evidence of a climate and Q fever relationship at this time.

3.4.5 Other Environmental Infectious Diseases

Valley Fever

Valley fever (coccidioidomycosis) is caused by fungi in the *Coccidioides* genus (CDC 2015j). It is found in the soils of dry, low rainfall areas and is endemic in parts of the southwestern United States (CDC 2015j). Humans can develop valley fever by breathing in *Coccidioides* spores in the air, although most people who breathe in the spores don't get sick (CDC 2015j). With rainfall generally predicted to increase in Vermont, the threat of coccidioidomycosis is unlikely to increase with the changing climate.

Anthrax

Anthrax is a serious and potentially lethal infectious disease that can be found naturally in soil and commonly affects domestic and wild animals and occasionally is transmitted to humans (CDC 2015k). While warming temperatures and greater precipitation may create a more favorable environment for the anthrax bacterium, there are currently only between 1 and 2 cases of anthrax annually in the whole of the United States (CDC 2015k). Anthrax is thus unlikely to be a major climate-related health concern in Vermont.

3.5 Foodborne and Waterborne Diseases

Food and waterborne diseases represent a substantial public health burden in the United States. Annually, an estimated 48 million Americans become sick, about 128,000 are hospitalized and about 3,000 die from foodborne illness (CDC 2014f). Additionally, an estimated 19.5 million cases of waterborne disease occur each year from public water systems alone, though the burden of illness from private water sources and recreational water-use are poorly quantified (CDC 2013f). Table 14 summarizes the recent health burden of Vermont's most common foodborne and waterborne diseases.

Table 14: The most common foodborne and waterborne diseases in Vermont. Cases reported in 2013 (up to November) and 5-year median (up to November 2013)

Disease	Cases in 2013	5-year median (2008-2013)	Most likely transmission
Campylobacter	179	179	Foodborne
Giardiasis	157	176	Waterborne
Salmonellosis	68	76	Foodborne
Cryptosporidiosis	36	68	Waterborne
E.Coli (STEC)	20	20	Foodborne
Legionellosis	14	11	Waterborne
Hepatitis A	2	7	Foodborne
Shigellosis	3	4	Foodborne
Listeriosis	1	1	Foodborne

Generally, the same pathogen can be foodborne or waterborne, though some pathogens are more strongly associated with one or the other medium. Pathogens can be bacteria, viruses, or single-cell protozoan parasites. Most commonly, foodborne and waterborne pathogens result in gastrointestinal illness. Many of these diseases probably go unreported, with those infected recovering fairly quickly. However, severe complications can occur, particularly among the elderly (Luber et al. 2013).

Increasing heavy precipitation and increasing temperatures are expected to create a more favorable environment for foodborne and waterborne pathogen proliferation and transport (Belanger et al. 2009; English et al. 2009; Frumkin et al 2008; Luber et al. 2013; Portier et al. 2010). Heavy precipitation heightens the likelihood of sewer and septic overflow, which can result in the release of contaminated wastes into the environment. Heavy precipitation also increases runoff from other contaminated areas, such as agricultural fields, which can be impacted by pathogens associated with cattle, including cryptosporidium or *E.coli* (Curriero et al. 2001). In addition to increasing the chances of contamination of drinking water supplies, intense runoff can add otherwise benign organic materials to water supplies that lessen the effectiveness of disinfectants (Curriero et al. 2001). About 37% of Vermonters rely on small water systems serving less than 3,300 people for their drinking water, compared to the national proportion of 9% (DEC 2013). Small water systems generally lack the resources of larger urban systems and can be more vulnerable to fluctuations in raw-water quality. Furthermore, many Vermonters rely on untreated groundwater from private wells as their chief source of water. Untreated water sources may be at greater risk for contamination (Luber et al. 2013). Precipitation-driven contamination can also impact recreational waters and cause disease among beach-goers, boaters, and other users (Frumkin et al. 2007).

Foodborne illnesses peak in the summertime, though some of this peak may be related to the fact that outdoor food preparation is more common in the summer (USDA 2013). An additional area of concern for food safety is the possibility of more frequent power outages due to extreme weather events, which can lead to faster spoiling of food.

Climate change may also result in increased pesticide use, as described in Section 3.7. In combination with increased extreme precipitation, this is expected to result in greater loads of chemical residues to water bodies. More extreme precipitation can also increase leaching from industrial sites and hazardous waste sites into waterways (Portier et al. 2010). Cumulatively, these changes would result in higher human exposure to pesticide and other chemical residues on food and in water.

Sea-food poisoning and climate change

Section 3.6 discusses how the changing climate may affect the occurrence of toxic algal blooms. That section focuses on freshwater blooms, as these are of primary concern in landlocked Vermont. However, marine blooms (those occurring in the ocean) may increase in magnitude and occurrence (Luber et al. 2013; IPCC 2001), thus contaminating seafood imported into Vermont. The most common diseases caused by marine biotoxins are paralytic, neurotoxic, and amnesic shellfish poisoning, as well as ciguatera (CDC 2007b). While shellfish poisonings are rare, paralytic and amnesic shellfish poisoning are particularly dangerous and can be fatal (CDC 2007b). About 30 cases are reported in the United States each year (CDC 2007b). Probably more such poisonings occur, but many of these may be fairly mild. Additionally, about one death occurs nationwide every six years. Thus even if the incidence of severe poisoning were to increase several fold, it may still have a very limited impact in Vermont.

Of greater concern to Vermont is the threat of an increase in contamination of shellfish by estuarine bacterial species, particularly those of the genus *Vibrio*. These include *Vibrio vulnificus, Vibrio parahaemolyticus,* and *Vibrio cholera* (CDC 2007b). *V. vulnificus* and *V. parahaemolyticus* can cause vibriosis. Vibriosis is characterized by watery diarrhea, vomiting and abdominal cramps. *V. vulnificus* can also cause primary septicemia (blood poisoning). Bloodstream infections usually occur in people who are immunocompromised or have chronic liver conditions. Half of cases of bloodstream infection by *V. vulnificus* result in death (CDC 2013g). Each year, vibriosis results in an estimated 80,000 cases, 500 hospitalizations and 100 deaths in the United States (CDC 2013g). Vibriosis became a notifiable condition in 2007. *V. cholera* causes the disease cholera, which is characterized by severe and potentially fatal diarrhea if it is not treated promptly. Cholera is a notifiable disease. Cholera is generally contracted as a waterborne disease in regions with poor water and sanitation conditions. Because of this, it is currently rare in the United States. However, it can also be contracted through eating contaminated and undercooked or raw shellfish. *Vibrio* species fare better in warmer waters (IPCC 2007). With warming sea temperatures, contamination of seafood by *Vibrio* species may become more common, even when seafood is sourced from temperate areas (Portier et al. 2008).

3.6 Harmful Algal Blooms (HABs)

Algae and other microorganisms are an important component of healthy marine and freshwater ecosystems (CDC 2015L). However, under specific environmental conditions, these microorganisms can form large colonies, or blooms, that can deplete dissolved oxygen supplies and block sunlight, thus impacting other aquatic organisms. Furthermore, some aquatic microorganisms produce toxins that, when released from blooms, can reach concentrations high enough to harm human health (CDC 2015L).

Vermont is a landlocked state. Marine algal blooms are thus not of direct concern, except where they contaminate imported fish and shellfish, as discussed in Section 3.5. However, freshwater blooms caused by cyanobacteria are a direct threat to Vermont's extensive inland water resources. Vermont's lakes provide a recreational resource for both residents and tourists and are an important supply of drinking water to many communities. The risks of cyanobacterial exposure are therefore of great concern.

As the name implies, cyanobacteria are not true algae, but rather bacteria. They are nevertheless frequently referred to as "blue-green algae" due to their color. There are many different kinds of cyanobacteria, some of which produce toxins. The two main categories of cyanobacterial toxins most commonly encountered in Vermont, and their associated health effects, are summarized in Table 15.

Table 15: Select Cyanotoxins (adapted from EPA 2012)

Cyanotoxin	Primary organ affected	Health effects
Microcystin-LR	Liver	Abdominal pain, vomiting, diarrhea, liver inflammation and hemorrhage, acute pneumonia, acute dermatitis, kidney damage, potential tumor growth promotion
Anatoxin-a group	Nervous system	Tingling, burning, numbness, drowsiness, incoherent speech, salivation, respiratory paralysis leading to death

While at high concentrations the toxins produced by cyanobacteria can be extremely dangerous, exposures actually experienced in natural environments are usually fairly low. There are in fact no recorded cases of human illness from cyanotoxin exposure in Vermont. However, cyanobacterial blooms on Lake Champlain were associated with two dog deaths in 1999 and 2000 (VDH 2014b).

Globally, the occurrence of harmful algal blooms appears to be on the rise (EPA 2013; Luber et al. 2013; Moore et al. 2008). The changing climate may be playing a role in this increase (Belanger et al. 2008; English et al. 2009; Frumkin et al. 2007; Luber et al. 2013; Portier et al. 2010). However, the mechanisms of bloom formation and of toxin production are mediated by a variety of factors in addition to climate. Because of this, it is difficult to predict with certainty the effects of climate change on the occurrence of harmful algal blooms. There are nevertheless several pathways by which the changing climate could result in a more favorable environment for cyanobacterial bloom formation (EPA 2013; Moore et al. 2008). These mechanisms are driven by:

1) *Warmer temperatures*: warmer water temperatures can lead to greater thermal layer stratification, which resist the mixing effect of winds (EPA 2013). This allows cyanobacteria to form as a sheet-like bloom in the warm top water layer, in turn blocking sunlight to competing organisms (EPA 2013). Additionally, warmer waters have lower viscosity and thus provide less resistance to cyanobacteria floating towards the surface (EPA 2013).

2) *Increases in atmospheric carbon dioxide concentrations*: cyanobacteria perform photosynthesis, and need carbon dioxide from the atmosphere to grow. Higher atmospheric carbon dioxide concentrations increase the available supply of carbon for cyanobacteria. Cyanobacteria floating near the surface are at a particular advantage as they can directly incorporate carbon dioxide from the atmosphere (EPA 2013).

3) *Changes in rainfall patterns:* increased rainfall and particularly increases in intense rainfall could lead to greater runoff of sediments and nutrients, notably phosphorus and nitrogen, into water bodies. Increased nutrient levels would create a more favorable environment for cyanobacterial and other HABs (EPA 2013).

Some of these potential drivers of cyanobacterial bloom growth can also be constraints. For instance, higher carbon dioxide concentrations lead to water acidification, which in turn can create a less favorable environment from cyanobacteria (Moore et al. 2008). Similarly, while extreme precipitation may lead to increased loading of nutrients into water bodies, they may also help break blooms up. While new knowledge is being generated, the complex interplay of environmental factors that lead to bloom formation remain poorly understood and as a result, reliable quantitative projections of future bloom occurrence remain out of reach (Moore et al. 2008).

Trends in the occurrence of cyanobacterial blooms in Vermont themselves also leave unanswered questions. Most Vermont studies dealing with cyanobacterial blooms have been carried out on Lake Champlain. The Department of Environmental Conservation (DEC) began incorporating cyanobacetrial monitoring into it long-term lake monitoring plan in 2002. However, sampling episodes from 1970 to 1974 and 1991 to 1992 allow for the observation of longer-term trends. Over the 1970 to 2006 period, there appears to have been a spatial shift in the prevalence of cyanobacterial prevalence in Lake Champlain (Smeltzer et al. 2012). In the 1970's, detections were being made in South Lake and St. Albans Bay but not in Missisquoi Bay, Malletts Bay or the Northeast Arm. Since 2006 however, cyanobacteria, though still common in St. Albans Bay, have become rare in the South Lake. Conversely, they have become common in Missisquoi Bay, Malletts Bay and the Northeast Arm (Smeltzer et al. 2012). The contribution of different environmental factors to this shift isn't known for certain.

Increasing temperatures likely play a role in this shift. Average August surface water temperatures have risen by 0.035 to 0.085°C per year over the 1964 to 2009 period (Smeltzer et al. 2012). This rate of warming is faster than that of the ambient air temperature around Lake Champlain over the same time period (Smeltzer et al. 2012). Warming could have a particularly powerful impact in shallow areas, such as Missisquoi Bay, where heating of the water-sediment interface could increase release of phosphorus from the sediment (Smeltzer et al. 2012). However, over the same time period, several other substantial environmental changes occurred that could have affected impacted cyanobacterial patterns, including the introduction of invasive species such as zebra mussels and alewife (Smeltzer et al. 2012). Additionally, over the 1979 to 2009 period, extensive efforts to limit phosphorus loading resulted in a stabilization or decline in total phosphorus in many regions of the lake (Smeltzer et al. 2012). However, total phosphorus continued to increase in the Northeast Arm, Malletts Bay, Shelburne Bay, and particularly Missisquoi Bay, where it rose by 72% (Smeltzer et al. 2012). Over the 1979 to 2009 period, total nitrogen loading into the lake was cut by around 18% (Smeltzer et al. 2012). Over the same time period, concentrations of chlorophyll-a, which is a general indicator of phytoplankton biomass, stayed fairly constant in all areas of the lake, other than Missisquoi Bay, in which they doubled (Smeltzer et al. 2010).

In short, the interplay of climate and various other environmental factors with cyanobacterial prevalence in Vermont's lakes is complex and remains poorly understood. Fortunately, there are several monitoring programs in Vermont that may deepen our understanding of climate and bloom relationships. In addition to the DEC's ongoing monitoring program in Lake Champlain that was discussed earlier, the Lake Champlain Committee (LCC) has led a volunteer-implemented cyanobacterial bloom monitoring program on Lake Champlain since 2002. Initially a lab-based monitoring program, it now monitors 54 shoreline sites weekly throughout the summer using visual evaluations. In the summer of 2013, the Vermont Department of Health, funded by CDC's Climate Ready States and Cities Initiative and assisted by the LCC and DEC, began weekly visual and laboratory evaluations at 12 sites on Lake Champlain as well as on Lakes Memphremagog, Carmi, Elmore and Iroquois. Laboratory analysis includes cell counts by microscope analysis and testing for microcystin-LR and anatoxin-a. The Health Department compiles its own monitoring data as well as that of the DEC and LCC monitoring efforts on a web portal, in an effort to inform swimmers and other lake users of the location of blooms. Over the long term, this data repository may shed clues on how Vermont's changing climate is affecting bloom formation.

3.7 Food Insecurity

Food security means access by all people at all times to enough food for an active, healthy life (USDA 2013). Adequate and appropriate nutrition is vital to good health, disease prevention and the healthy development of children and adolescents (CDC 2015m). A lack of food security, or food insecurity, is thus different from hunger. Hunger is the painful sensation caused by a lack of food and is an extreme manifestation of food insecurity. However, health impacts of food insecurity can arise long before hunger becomes evident. For instance, to avoid hunger, food insecure families may turn to calorie-rich but nutrient-poor foods, which can result in a range of health effects, including macronutrient malnutrition and obesity (Luber et al. 2013). Food insecurity already affects an estimated 13.1% of Vermonters (Feeding America 2011). While this number is somewhat lower than the national proportion of 16.4%, it represents some 81,750 individuals, of which about 23,670 are children (Feeding America 2011). The average cost of a meal in Vermont is $2.94, higher than the national average of $2.67 (Feeding America 2011).

Unfortunately, climate change is expected to threaten global food production and by extension raise food costs (Belanger et al. 2008, Frumkin et al. 2007, Luber et al. 2013). Crop yields are generally expected to decline due to shifting rainfall patterns, increases in extreme-weather events and increasing competition form weeds and pests (Luber et al 2013). Globally, livestock and fish production are also expected to decrease (Luber et al. 2013).

In the United States, climate change is expected to impact agriculture through four key pathways (Hatfield et al. 2013). These pathways are described in the sections below.

1) Crop response to rising temperatures and increasing atmospheric carbon dioxide: While warming temperatures may increase growth rates and growing seasons for some types of crops in some areas, they are expected to have adverse effects on the yields of some crops. For instance, elevated nighttime temperatures are associated with decreased production of grains in crops such as corn (Hatfield et al. 2013). Furthermore, many fruit crops require a threshold number of hours between 32 and 50°F, known as chilling hours, to achieve high yields. Some regions have already experienced a 30% reduction in chilling hours since 1950 (Hatfield et al. 2013). Similarly, while higher atmospheric carbon dioxide concentrations tend to increase the growth rate of many crops, they are also associated with lower nitrogen and protein content of products such as alfalfa and soybean, which results in a lower nutritional value (Hatfield et al. 2013).

2) Increasing threat from pests: Higher carbon dioxide concentrations stimulate plant growth. The rate of plant growth varies by plant. Several common weeds are disproportionately stimulated by higher carbon dioxide levels. These weeds are thus anticipated to compete more effectively with crops as carbon dioxide levels continue to increase (Hatfield et al. 2013). Furthermore, in laboratory tests simulating the carbon dioxide levels that are anticipated by end of the century, the herbicide glyphosate has been found to lose much of its efficacy (Hatfield et al. 2013). Glyphosate, which includes brands such as RoundUP™, is the most commonly used herbicide in the United States (Hatfield et al. 2013). Increasing humidity is also expected to increase the amount of insect and microbial pests. Earlier spring and warmer winter conditions may provide more favorable environments for the proliferation of diseases, including anthrax, blackleg and hemorrhagic septicemia, and as a result may lead to increased incidence of ketosis, mastitis and lameness in dairy cows (Hatfield et al. 2013).

3) Extreme precipitation impacts on soil and water quality: With the frequency and intensity of extreme precipitation events expected to increase throughout much of the country, the rate of soil erosion is likely to increase as well (Hatfield et al. 2013). Quality soils are a valuable component of agricultural systems. Once soils are eroded away, they are not easily replaced. Furthermore, runoff carrying soils, fertilizers and pesticides can severely degrade the quality of receiving waters (Hatfield et al. 2013).

4) Heat and Drought: Extreme heat events can have substantial impacts on the productivity of livestock. Dairy and egg production tend to decline, as does the rate of weight gain of meat animals (Hatfield et al. 2013). Extreme heat events can also decrease livestock conception rates (Hatfield et al. 2013). Drought, characterized by multi-day periods of little or no precipitation, can have severe impacts on crop production (Hatfield et al. 2013).

In the United States, adaptations to the changing climate have to date been generally successful, as demonstrated by the continued increase in productivity (Hatfield et al. 2013). These adaptations have included changes in crop selection, timing of field operations and increasing pesticide use (Hatfield et al. 2013). However, with a projected acceleration in climate change, more transformative adaptations may be needed in the future (Hatfield et al. 2013).

Vermonters get much of their food from outside of the state and are thus susceptible to the changes described above. However, Vermont is itself an agricultural state. Dairy accounts for 70-80% of Vermont's agricultural sales (Dunnington 2010). Maple syrup production is another important industry, with annual revenues of approximately $200 million (Dunnington 2010).

With 94 farmers' markets and 139 Community Supported Agriculture organizations (CSAs) the state arguably leads the nation in local food sourcing (Strolling of the Heifers 2013). This active and diversified local agriculture system may buffer disruptions to the global food system. Local agriculture however is also susceptible to climate change impacts.

The Vermont Agency of Agriculture's white paper on climate impacts (Dunnington, 2010) summarizes climate change concerns for the State's agricultural sector as:

1) Increased spread of pests and pathogens, which may pressure farmers into heavier use of pesticides and herbicides, or, in the case of organic farms, more labor-intensive weed and pest control.
2) Decreased milk productivity in dairy cows: annual losses to Vermont dairy due to heat stress are already estimated at $5.3 million per year (St. Pierre et al. 2003).
3) Increased erosion due to increases in precipitation and resultant storm water runoff, causing loss of field crops as well as soil depletion.
4) Increased variability in first and last frost dates, increasing the risk of crop failure.
5) Increases in short-term drought events, which may necessitate a greater demand for and expense of irrigation.
6) Decrease in the productivity of cold-weather crops.

Tropical storm Irene also highlighted the vulnerability of Vermont's crops to flooding events. However, countering some of the negative impacts listed above, the Agency of Agriculture also anticipates an increase in productivity of warm-weather crops and a lengthening of the growing season. Delving into the details of the impacts of climate change on Vermont's agriculture is outside of this report's scope. For the purposes of forecasting the changing climate's impacts on local food supply, it is currently difficult to say how the local food system's output will change. Local food production is likely to become more variable, but if sound management practices are implemented and maintained, it could potentially increase its output over current levels. Whether this increase in local production would offset the impacts of declines in national and global production is unclear.

3.8 Threats to Mental Health

Mental illnesses are defined as conditions characterized by alterations in thinking, mood, or behavior and associated with distress and/or impaired functioning (CDC 2013h). Mental illnesses represent a tremendous public health challenge. Some published studies estimate that about 25% of all U.S. adults have a mental illness and that nearly 50% of U.S. adults will develop at least one mental illness during their lifetime (CDC 2011b). The economic costs of mental illness are estimated to be in excess of $300 billion per year (CDC 2011b).

Anxiety disorders, which include panic disorders, generalized anxiety disorder, post-traumatic stress disorder, phobias and separation anxiety disorder, are the most common class of mental health illness. About 15% of the U.S. population suffers from an anxiety disorder at some point in their life, while the 12-month prevalence is in excess of 10% (CDC 2013h). Depression is also a very common class of mental illness, with a lifetime prevalence of close to 9%. Some studies have estimated that about 7% of the population has had a major depressive episode in the last 12-months (CDC 2013h). Frequent mental distress, defined as the experience of stress, depression, and emotional problems on 14 or more days out of the last 30 days, has a prevalence of about 9.4% (CDC 2013h).

Over 7% of adult Vermonters report depression (VDH 2012). This figure rises sharply to 17% among Vermonters who are part of an ethnic minority. It is also higher among youths, nearing the 20% mark among high school students. Furthermore, Vermont's suicide rate is 13 per 100,000, higher than the US rate of 11 per 100,000.

Climate change may exacerbate or trigger mental illness (Belanger et al. 2008; Frumkin et al. 2007; Luber et al. 2013; Portier et al. 2010). There are four suggested principal avenues through which such impacts could occur (Luber et al. 2013). These pathways are described below.

1) *The traumatic effects of catastrophic weather events:* High levels of anxiety and post-traumatic stress disorder have been found among people affected by catastrophic events, such as Hurricane Katrina, major flooding, heat waves and wildfires (Luber et al. 2013).
2) *The impact of heat on certain mental illnesses*: Certain mental illnesses appear to be exacerbated by extreme heat. A study of suicides across England and Wales, for instance, found an incremental increase in the daily suicide rate of 3.8% per 1.8°F rise in temperatures over 64°F (Page et al. 2007). The same study found what appeared to be a 47% increase in daily suicides during a heat wave in 1995, though no such increase was observed in a subsequent heat wave in 2003 (Page et al. 2007). Several mental illnesses also reduce an individual's thermoregulatory capacity, either directly, as can be the case with schizophrenia, or through the side effects of certain medications used to treat mental illnesses, such as anticholinergic medications (Cusack et al. 2011).
3) *Distress associated with environmental degradation and displacement:* Separation from a loved home through displacement is associated with a range of psychological stresses. Environmental degradation, on the other hand, can change a loved home to the point where the psychological impacts are similar to leaving that home, a concept referred to as solastalgia (Albrecht et al. 2007). As the climate and vegetation of Vermont change, some of the things that make Vermont quintessentially Vermont, such as maple sugaring, ice-fishing, snowy winters and fall colors, to name but a few, may be altered substantially.
4) *Anxiety and despair about climate change:* Similarly to the distress experienced by those living near hazardous waste sites, the chronic stress from the knowledge of a rapidly and potentially dangerously changing world can create stress-related symptoms (Doherty and Clayton 2011).

Unfortunately, information on the relationship between current climate threats in Vermont and mental health impacts is virtually inexistent. Thus making quantitative estimates of the future disease burden is very difficult. However, projections of extreme heat and extreme weather events are available, thus shedding some light on how the first two avenues of impact described above may change over this century. Also, a 2014 Middlebury College Environmental Studies Senior Seminar project addressed some of the potential mental health impacts of climate change in Vermont (Middlebury College 2014).

3.9 Potential Exposures from Primary Mitigation Technologies

Of the five reports reviewed, only one mentioned potential exposures from primary mitigation technologies as an area of concern (Portier et al. 2010). Mitigation technologies are those whose use may be increased in an effort to reduce greenhouse gas emissions. Such technologies include electric vehicles, wind turbines and solar panels. Greater use of such technologies could result in exposures to potentially harmful compounds (Portier et al. 2010). For instance, a large expansion in the use of nickel-metal-hydride batteries in vehicles could lead to greater exposure to nickel. Additionally, an increase in demand for nickel could result in the ramping-up of nickel mining and production in certain areas, which has previously been associated with increased cancer risk, respiratory disease and birth defects (Portier et al. 2010). Another example of a mitigation-related exposure would be from an increase in pesticide use related to biofuel production (Portier et al. 2010). However, while such concerns are certainly valid and must be considered as solutions to manage climate change are developed, they are beyond the scope of this report, which is focused on climate impacts alone rather than on the impact of technologies aimed to attenuate it. Additionally, there are a wide variety of health benefits associated with the widespread adoption of mitigation technologies, such as better air quality associated with a reduced use of fossil fuels (Markandya et al. 2009).

3.10 Population Dislocation

Large migrations can have substantial health implications for both displaced and host populations. Population movements broadly fall into three categories: 1) forced displacement, 2) planned resettlement and 3) migration (McMichael et al. 2012). Climate change impacts may lead to increased population movements through all of these mechanisms (Belanger et al. 2008; Frumkin et al. 2007; Portier et al. 2010). Forced displacement may occur as climate change undermines certain groups' ability to continue living in their original place of residence (McMichael et al. 2012). This type of displacement would be primarily driven by extreme weather events, such as drought or severe storms, particularly coastal storms exacerbated by sea-level rise (Myers 2002). These displacements would likely tend to occur over short distances and within countries (McMichael et al. 2012). The term "climate refugee" is sometimes used to describe those affected by climate-driven forced displacements. However, the term "refugee" has an internationally accepted definition implying a threat from prosecution and displacement across an international border and should probably be avoided in the climate change context (Brown 2008). The exception being when the effects of climate change contributes to a rise in conflict and by extension a flow of refugees, as was the case in the recent conflict in the Horn of Africa fueled in part by drought and famine (McMichael et al. 2012).

Planned resettlement is an adaptation strategy to environmental change. Individuals in areas deemed at risk can be encouraged, by policy measures, to move to other locations (McMichael et al. 2012). A recent example of such an initiative is the "Acquisition and optional relocation program" that was implemented by New York City in the wake of Hurricane Sandy to help home owners in high-risk areas relocate (NYC-HPD 2014).

Migration is a broad term designating population movement. It can be a combination of a push from worsening conditions in the initial place of residence as well as the pull of greater opportunity in other areas (Brown 2008). For instance, greater aridity in some regions may lead to a progressively weaker economy and may induce a flow of migrants into more agriculturally productive areas.

Quantifying the contribution of climate change to the global pool of environmental migrants is a very difficult task. A widely cited projection predicts about 200 million additional environmental migrants by 2050 (Myers 2002). To put this number into perspective, the International Organization for Migration estimated that there are a total of 192 million people currently living outside of country of their birth (Brown 2008). This would mean that about 1 in every 45 people would be displaced by climate change by 2050 (Brown 2002). However, any projection of climate migration relies on many assumptions. As a result, published projections of the increase in environmental migration vary between 25 million and 1 billion by 2050 (Brown 2008). Nevertheless, even the low estimate of 25 million is more than double the 10.4 million international refugees estimated to have been displaced by conflicts in Syria, sub-Saharan Africa and elsewhere in 2013 (UNHCR 2013)

Vermont may be impacted by all three forms of population dislocation. Firstly, Vermont may experience forced displacement in river corridors during and after flooding events. For instance, over 1,400 households were permanently or temporarily displaced after Tropical Storm Irene (ANR 2011). Vermonters may turn to planned resettlement as an adaption strategy in the face of flooding risk. Finally, Vermonters may migrate within or out of the state as economic opportunities become affected by climate change. For instance, a decline in the ski industry may lead to population shifts.

Of equal or greater concern to Vermont is the potential for an influx of environmental migrants from elsewhere. Environmental migrants could hail from more vulnerable regions within the United States as well as overseas. Vermont’s inland and northern location provides a measure of adaptive advantage over many coastal or more arid areas, which may make it a comparatively appealing destination.

Since 1980, Vermont has been a member of the Federal Refugee Resettlement Program. Between 1989 and 2013, the program resettled over 6,000 refugees in Vermont, primarily in Chittenden County (Vermont State Refugee Coordinator, 2014). However, a rise in climate-driven global conflict, while likely generating more refugees, would not necessarily result in more resettlement. This is because every year, the federal government in collaboration with its in-state partners, determines the region’s carrying-capacity for new refugees, thus constraining the numbers.

However, Vermont’s refugee population is only a fraction of the over 25,000 Vermonters who were born outside of the country (USCB 2014). A total of 2,269 people moved to Vermont from a foreign country in 2012 (USCB 2012). By comparison, in 2012, only 350 refugees had arrived to Vermont (Vermont State Refugee Coordinator, 2014). The vast majority of voluntary migrants to the United States settle in large urban areas (Vermont State Refugee Coordinator, 2014). An increase in migration to the United States would probably affect large urban areas first. An exception to this trend may be the flow of agricultural migrants. A shift in Vermont agriculture to warmer-weather crops and longer growing seasons, combined with severe climate effects on agriculture in other regions of the Americas may result in an increase in the migration of farm workers to Vermont. The non-profit group Vermont's Migrant Justice estimates that there are some 1,200 to 1,500 migrant workers in the state at present, employed largely in the dairy industry, though a precise number is difficult to ascertain (Migrant Justice 2014).

The greatest source of migration to Vermont is from other States (USCB 2012). In 2012 for instance, about 24,000 people moved to Vermont from other states, with New York, New Hampshire, Pennsylvania, Massachusetts, Florida, Connecticut and California leading as the states of origin (USCB 2012). Meanwhile, 20,000 people left Vermont over the same period, resulting in a net immigration of about 4,000 (USCB 2012). Migration from other states could foreseeably increase with the changing climate, particularly from coastal states. However, in discussions of migration to Vermont, it must also be noted that Vermont's net population growth between 2010 and 2013 was estimated at 0.1%, nearly stagnant compared to the national average growth of 2.4% over the same time period (USCB 214).

3.11 Civil Conflict

Climate change may contribute to the occurrence and scale of armed conflict (Frumkin et al. 2007). Drought in the Horn of Africa in 2011 for example exacerbated the conflict there (McMichael et al. 2012). In addition to dislocating populations, such conflicts could draw-in US forces, which could include Vermonters. In recognition of the geopolitical impacts of climate change and its potential to accelerate instability and conflict, the US Department of Defense has begun integrating climate change into its planning processes (Pellerin 2013). However, estimating the health impacts of future conflicts on Vermonters, let alone the contribution of climate change to these impacts would be an exercise crippled by uncertainties. While recognizing an upsurge in conflict as a real risk, the Department of Health refrains from making attempts to assess its associated health risks.

3.12 Ice Hazards

With warming winter temperatures, the strength of icing over water bodies is declining. A fall through ice can result in severe, even fatal, hypothermia or drowning. Ice safety was deemed a critical climate-related health issue by Canadian health officials in northern areas of Canada (Belanger et al. 2008). In these regions, frozen lakes or rivers as well as sea ice are frequently used for transportation or as hunting. Given the popularity of ice fishing, snowmobiling, and other winter outdoor recreation in Vermont, combined with the clear warming trend in Vermont's winters, the threat of thinning ice is of concern here as well. However, Vermont's vital records show only 2 drownings and 1 hypothermia case related to a fall into water over the winters of 1999 to 2012. Furthermore, the length of time during which lakes will be frozen will decrease, in turn decreasing some of the risk associated with ice-related activity.

Ice-related falls and motor vehicle collisions are likely to be a more significant concern in the future. An increase in the frequency of ice storms and freeze/thaw cycling during winter may increase the risk for injuries or fatalities related to slick conditions. Unfortunately, climate projections do not allow for predicting icing or freeze/thaw frequency with any confidence.

3.13 Sea-Level Rise

The latest IPCC assessment projects that by the end of the century, under the A2 scenario, mean sea level will rise by 1.5 to 2.7 feet above the 1985-2005 baseline (IPCC 2013). This rise would likely result in substantial impacts, including injuries and drownings during storm surges, water and soil salinization, and ecosystem and economic disruption (Belanger et al. 2008; English et al. 2009; Frumkin et al. 2007; Luber et al. 2013; Portier et al. 2010). Sea level rise is global in its impact, and Vermont would likely experience its indirect effects through migration and economic disruption. However, Vermont is a landlocked state, with its minimum elevation being of 95 feet at Lake Champlain. So, direct effects of sea level rise on human health in Vermont are not anticipated over this century.

3.14 Stratospheric Ozone Depletion

The risks posed by stratospheric ozone depletion ("the ozone hole") and climate change ("the greenhouse effect") are frequently confused. This may be because chlorofluorocarbons (CFCs), the compounds primarily responsible for stratospheric ozone depletion also act as powerful greenhouse gases contributing to climate change (IPCC 2013). The processes are also related because climate change is associated with an intensification of the polar vortex, which concentrates CFCs and other ozone-destroying gases above the poles. This results in a delay in the anticipated recovery of stratospheric ozone concentrations. Though the link between stratospheric ozone depletion and increased risk of certain skin cancers and cataracts is well established (Portier et al. 2010), this threat to the public health is being addressed through other Health Department initiatives rather than as part of the Climate and Health Adaptation Program.

4. Vulnerable Populations

This section lists specific vulnerable groups that the Climate and Health Adaptation Program and its partners will need to consider in developing adaptation strategies. More detailed characteristics of vulnerable groups are likely to emerge as part of a vulnerability assessment conducted by the Climate Change Adaptation Program. Vulnerabilities were discussed briefly in Section 3 by exposure area. Here, the focus is on the vulnerable groups themselves, with relevant exposures summarized for each. Please refer to the relevant sub-sections for each exposure in Section 3 if more detail is desired, including references from the literature.

4.1 Elderly Vermonters

Vermonters of 65 years of age and older account for 16% of the state's population, compared to the national proportion of 14% (USCB 2014). In 2010, the median age of Vermonters was 42 years, compared to the national median of 38 years. And the state/national age gap has been widening, from about two years in 2000 to four years in 2010. More than one-third of Vermonters (37%) are between the ages of 40 and 64 (VDH 2012). So, a large percentage of Vermonters will be senior citizens in the future. Vermonters over 65 are at increased risk from a number of the climate-related exposures, including:

- Air quality impacts
- Extreme heat events
- Extreme weather events
- Vector-borne and other infectious diseases
- Foodborne and waterborne diseases
- Ice hazards

4.2 Children

Vermonters under the age of 5 account for 5% of the state's population (USCB 2014). Exposures of particular concern for this group include:

- Air quality impacts
- Extreme heat events
- Extreme weather events
- Vector-borne and other infectious diseases
- Foodborne and waterborne diseases
- Food insecurity
- Harmful algal blooms
- Ice hazards

4.3 Outdoor recreationalists

The number of Vermonters that engage in outdoor recreation activities, as well as the time spent engaged in those activities, are difficult to estimate. However, Vermont is known for its outdoor recreational opportunities, including hiking, swimming, biking, climbing, skiing, fishing and hunting. Some indicators of the extent of engagement in outdoor recreation are available however. For instance, the Department of Fish and Wildlife issues about 75,000 hunting licenses each year, representing 12% of the total population (WCAX 2013). Additionally, Vermont residents spend over 238,000 days visiting state parks and over 152,000 nights camping in state parks (Gilbert and Manning, 2002). Vermonters engaging in outdoor recreation are at greater risk from:

- Air quality impacts
- Extreme heat
- Extreme weather events
- Vector-borne and other infectious diseases
- Harmful algal blooms
- Foodborne and waterborne diseases
- Ice hazards

4.4 Outdoor workers

Data on the total number of Vermonters that work outdoors is not currently available. However, some 20,000 Vermont workers are employed in the agricultural, mining and construction sectors (VDOL 2012). Outdoor workers are at higher risk from:

- Air quality impacts
- Extreme heat events
- Vector-borne and other infectious diseases
- Population dislocation

4.5 Vermonters with asthma, allergies or other respiratory conditions

In the 2013 Behavioral Risk Factor Surveillance Survey (BRFSS), 16% of Vermont adults reported being diagnosed with asthma at some point in their lifetime, (~57,000 people). Additionally, 15%, of children in Vermont had current asthma (~13,000 children). The prevalence of both adult and childhood asthma in Vermont are higher than the national prevalence, which was 14% for both adults and children in 2013 (VDH 2014c).

Additionally, about 4.4% of Vermonters over 25 years of age have chronic obstructive pulmonary disease (COPD) (VDH 2014d). Data on the prevalence of seasonal or mold allergies is limited. Vermonters with respiratory conditions such as asthma or COPD at higher risk from:

- Air quality impacts
- Extreme heat events

4.6 Vermonters with cardiovascular conditions

More than 43,000 Vermonters, have some form of cardiovascular disease (VDH 2012). These diseases are higher among older age groups (VDH 2012). Vermonters with cardiovascular diseases are at greater risk from:

- Air quality impacts
- Extreme heat

4.7 Vermonters with a mental illness

Thousands of Vermonters suffer from mental illnesses. Among Vermont adults, 7% report depression (VDH 2012). Vermont's suicide rate is of 13 per 100,000 people, somewhat higher than the national rate of 11.3 per 100,000 people (VDH 2012). Vermonters with conditions such as depression may be at greater risk for an exacerbation of that condition by climate-related exposures, including:

- Extreme heat events
- Extreme weather events
- Threats to mental health

4.8 New Vermonters

Foreign-born Vermont residents account for 4% of the state's population (USCB 2013). While many of these are fully integrated into Vermont society, others find their vulnerability heightened by a lack of language skills and a lack of knowledge about local threats. This subset of new Vermonters is at particular risk from:

- Extreme heat events
- Extreme weather events
- Vector-borne and other infectious diseases

- Harmful algal blooms

4.9 Vermonters living in flood-prone areas

In 2012, 4,375 Vermont households and businesses were part of the National Flood Insurance Program (NFIP 2013). Since households and businesses in the 100-year floodplain must purchase NFIP insurance, this number is an approximation of the number of households within this zone. However, two-thirds of flood damages in Vermont occur outside of this zone (Vermont River Management Program 2008). Thus the number of households in flood-prone areas is likely much greater.

- Extreme weather events
- Foodborne and waterborne disease

4.10 Vermonters of low socio-economic status

About 12% of Vermonters are below the Federal poverty level (USCB 2013). The number of Vermonters that could be considered to be of lower socio-economic status is likely still greater. Those of lower socio-economic status tend to be overrepresented in several of the vulnerable groups already mentioned, including:

- Vermonters with cardiovascular diseases
- Vermonters with mental illnesses
- Vermonters with asthma or other respiratory diseases
- New Vermonters

By extension, this group is at greater risk from:

- Air quality impacts
- Extreme heat events
- Extreme weather events
- Threats to mental health

This group is also, by definition, at greater risk from:

- Food insecurity

Generally speaking, Vermonters of lower socioeconomic status are less likely to pursue costly adaptations, such as the purchase and use of an air-conditioning system, making them at greater risk for health impacts of extreme heat. Also, their ability to recover from flood and other weather damages may also be reduced.

4.11 Vermonters employed in climate-sensitive sectors

Climate-sensitive sectors include farming, maple sugaring, tourism and the ski industry. Without adaption, these sectors may become less viable, forcing a reduction in employment. Workers in these sectors would find themselves at greater risk for:

- Food insecurity
- Threats to mental health

4.12 Users of Private Wells and Small Water Systems

About 37% of Vermonters rely on small water systems serving less than 3,300 people (DEC 2013). This is in contrast to the national proportion of 9% (DEC 2013). Small water systems generally lack the resources of larger urban systems and can be more vulnerable to fluctuations in raw-water quality. Furthermore, many Vermonters rely on untreated groundwater from private wells as their chief source of water. Untreated groundwater may be at greater risk from climate impacts on water quality (Luber et al. 2013). These Vermonters are thus more vulnerable to:

- Foodborne and waterborne disease

5. Assessing Priority Climate and Health Risks

Due to resource and feasibility constraints, not all the areas of concern identified in Section 3 can undergo the full BRACE process. Instead, six exposures were selected as focus areas for the program. Exposures were initially evaluated on a set of six criteria. A numeric score was assigned to each criterion and the exposures were ranked in order of priority. A final selection was made from the high ranking areas based on their suitability for the BRACE process. The six selected focus areas are:

1) **Extreme heat events**
2) **Air quality impacts**
3) **Extreme weather events**
4) **Mosquito and tick-borne diseases**
5) **Foodborne and waterborne pathogens**
6) **Cyanobacterial blooms**

The renaming of some focus areas is explained in Section 5.2. The selection of focus areas was based primarily on the evaluation summarized in Table 16.

Table 16: Evaluation of Climate-Related Exposures

Exposure	Current health burden	Certainty of exposure increase	Magnitude of health burden increase by 2041-2070	Magnitude of health burden increase by 2070-2099	Current Vulnerability	Potential for State-led adaptation
Air quality impacts	High	Medium	High	High	High	Medium
Extreme heat events	High	High	High	High	High	High
Extreme weather events	Medium	High	High	High	High	High
Vector-borne and other infectious pathogens	High	High	Medium	High	High	High
Foodborne and waterborne pathogens	High	High	Low	Medium	High	High
Cyanobacterial blooms	Medium	Medium	Medium	Medium	High	High
Exposures from mitigation technologies	Outside of program scope					
Food insecurity	Medium	High	Low	Medium	High	Medium
Population dislocation	Low	Low	Low	Medium	Medium	Low
Civil conflict	Low	Medium	Low	Low	Low	Low
Threats to mental health	Medium	High	High	High	High	High
Ice safety	Low	Low	Low	Low	Medium	High
Sea-level rise	Not applicable					
Stratospheric ozone depletion	Outside of program scope					

The details of the selection are described in the sections below.

5.1 Evaluation of Exposures

Each exposure of concern identified in Section 3 was evaluated on the criteria described below. Criteria were graded as *low*, *medium* or *high*. Estimates were made based on available data, which for some exposures, was weak, necessitating a certain level of subjectivity.

1) **Current health burden related to exposure**
This assesses the extent to which the exposure is already resulting in adverse health outcomes.

   High: An estimated 100 Vermonters or more are made sick annually; or on average at least one Vermonter dies prematurely every year.
   Medium: At least five but less than 100 Vermonters are estimated to become sick annually because of the exposure; or some deaths occur due to the exposure, though on average less than one per year.
   Low/unknown: Fewer than five Vermonters are estimated to become sick annually because of the exposure; and no known deaths occur due to the exposure; or it is not clear whether there are current health impacts from this exposure.

2) **Likelihood of *exposure* increase**
This refers to the confidence that the exposure will increase (rather than decreasing or remaining constant). It does not refer to the magnitude of the change.

   High: the exposure is driven by a climate change effect that is projected to increase with high certainty.
   Medium: the exposure is affected by a climate change effect that cannot be projected with high certainty; or the exposure also depends on poorly understood non-climate factors.
   Low: projections do not agree on an increase or decrease; or the relationship between climate and the exposure is poorly understood to the point of not being known to be positively or negatively correlated; or projections suggest a decrease in the exposure.

3) **Potential magnitude of health burden increase by 2041-2070**
This refers to the magnitude of increase over the current health burden (rather than the exposure) by the 2041-2070 timeframe. This estimate assumes that no adaptation strategies are implemented. It also does not take population growth into account.
   High: initial estimates suggest an increase the health burden of 10% or more by the end of the time period.
   Medium: initial estimates suggest an increase in the health burden of less than 10% by the end of the time period
   Low: the magnitude of increase in the health burden is almost negligible

4) **Potential magnitude of health burden increase by 2070-2099**

This refers to the magnitude of increase over the current health burden by the 2041-2070 timeframe. This estimate assumes that no adaptation strategies are implemented. It also does not take population growth into account.

High: initial estimates suggest an increase the health burden of 10% or more by the end of the time period
Medium: initial estimates suggest an increase in the health burden of less than 10% by the end of the time period
Low: the magnitude of increase in the health burden is almost negligible

5) **Current vulnerability**
This assesses proportion of population that is at risk to the given exposure.
High: about 10% or more of Vermonters are at special risk
Medium: about 5% or more of Vermonters are at special risk
Low: Less than 5% of Vermonters are at special risk

6) **Potential for State-led adaptation:**
This assesses the ability of the State of Vermont or of partners within Vermont to lead the development of adaptation strategies.
High: the Health Department or its in-state partners can develop and implement adaptations with minimal outside support.
Medium: the Health Department and its in-state partners can play an important role in adaptation, but require external support.
Low: adaptation to the exposure must primarily be addressed outside of Vermont.

5.1.1 Air Quality Impacts

Current health burden related to exposure: **High**
While Vermont is in compliance with current National Ambient Air Quality Standards (NAAQS) for ground-level ozone, there is evidence that excess mortality and morbidity occur at levels below these standards (EPA 2013). For instance, the number of deaths due to ozone as modeled for Boston, if it were to attain an MDA8 of 60 ppb is of about 180 deaths per 100,000 people (EPA 2014). Assuming a similar relationship for Vermont, we expect to currently be seeing over 1,000 excess deaths in Vermont due to ozone every summer. Morbidity due to plant and other aero-allergens is very difficult to measure, though seasonal allergies are known to be widespread in the state.

Likelihood of exposure increase: **Medium**
The likelihood of exposure increase was based on individual assessment of several air quality components as described below.

Ozone: Medium. A threshold concentration of ozone precursors is required in order for warming temperatures to increase ozone production. Summertime precursor concentrations in Vermont are near this threshold, so it is not clear whether the state will see an overall increase or decrease in ozone concentrations.

PM2.5: Low. Generally speaking, a decrease in $PM_{2.5}$ is expected, both from condensation of precursor gases and from a decrease in wildfires in historic smoke source areas, though the latter may be countered to some extent by increases in fire risk in Maine and the Canadian maritime provinces.

Allergens: High. Rising atmospheric carbon dioxide concentrations and a longer frost-free season are very likely to increase allergen concentrations. Increased heat and humidity are also likely to result in enhanced mold growth.

Anticipated magnitude of health burden increase by 2041-2070: **High**
The most likely impact of climate change will be on increased allergens and mold growth. An expected increase in the frost-free season by 20 days and in carbon dioxide levels are both expected to increase allergen exposure. Warmer and wetter conditions, including the expected increase in heavy rain events that could lead to increased building flooding and moisture, are expected to lead to increased household mold. Increased ground-level ozone is expected in urbanized areas of the Northeast, but the impact of ozone on Vermont is highly uncertain. Particulate matter is expected to decrease as a result of reduced power plant and vehicular emissions, though it is possible that increased biomass combustion in Vermont could increase PM concentrations. Wildfire frequency in North America is expected to increase but it is challenging to assess the impact in Vermont with much certainty.

Anticipated magnitude of health burden increase by 2070-2099: **High**
The most likely impact of climate change will be on increased allergens and mold growth. An expected increase in the frost-free season by 40 days and in carbon dioxide levels are both expected to increase allergen exposure. Warmer and wetter conditions, including the expected increase in heavy rain events that could lead to increased building flooding and moisture, are expected to lead to increased household mold. Increased ground-level ozone is expected in urbanized areas of the Northeast, but the impact of ozone on Vermont is highly uncertain. Particulate matter is expected to decrease as a result of reduced power plant and vehicular emissions, though it is possible that increased biomass combustion in Vermont could increase PM concentrations. Wildfire frequency in North America is expected to increase but it is challenging to assess the impact in Vermont with much certainty.

Current vulnerability: **High**
Vermont's vulnerability to air quality impacts was deemed *high* primarily due to the high prevalence of asthma in the state. Adult asthma prevalence is estimated at 15.4%, higher than the national average of 13.3% (see *Asthmatics* in section 4).

Potential for State-led adaptation: **Medium**
While ambient air quality standards are set by the Federal Government and while much of Vermont's air pollution is generated outside of the state, the state nevertheless maintains an important role in reducing air pollution. Potential state-led actions include efforts to reduce air pollution from woody biomass combustion through stove exchange programs and further support to households and schools addressing mold issues, as well as continued efforts in asthma management and prevention. Vermont can also advocate for reductions in trans-boundary air pollution and is responsible for implementing revised federal standards.

5.1.2 Extreme Heat Events

Current health burden related to exposure: **High**
Initial epidemiological analyses suggest that several Vermonters die prematurely every summer due to extreme heat events. Furthermore, every summer, about 70 Vermonters go to the emergency department due to exposure to extreme heat.

Likelihood of exposure increase: **High**
Extreme heat events are projected to increase in Vermont.

Anticipated magnitude of health burden increase by 2041-2070: **High**
In the absence of adaptation or acclimatization, extreme heat events are expected to have a somewhat linear relationship with health outcomes. Dangerously hot days are expected to double by this time period, even under the B1 scenario, suggesting a doubling in mortality.

Anticipated magnitude of health burden increase by 2070-2099: **High**
In the absence of adaptation, extreme heat events are expected to have a somewhat linear relationship with health outcomes. Dangerously hot days are expected to more than triple by this time period, even under the B1 scenario.

Current vulnerability: **High**
Housing in Vermont has historically been adapted to extreme cold rather than to extreme heat. Furthermore, the elderly are considered to be particularly vulnerable to extreme heat events. With 16% of its population above the age of 65, Vermont is likely to be more susceptible to extreme heat. Finally, extreme heat events do not appear to be viewed as a credible threat by many in Vermont, creating an additional vulnerability based on flawed knowledge and attitudes.

Potential for State-led adaptation: **High**
A successful response to extreme heat-events would be largely community-driven. Adaptation to this threat will require coordination between state and local governments and community partners to ensure that vulnerable populations understand and are prepared for extreme heat.

5.1.3 Extreme weather events

Current health burden related to exposure: **Medium**
Flooding places a heavy economic burden on Vermonters, but the health impact of extreme weather events remains difficult to estimate. While deaths and physical injuries due to flooding are fairly rare, there is likely a significant though still unmeasured mental health burden.

Likelihood of exposure increase: **High**
The risk of extreme weather events is expected to increase.

Anticipated magnitude of health burden increase by 2041-2070: **High**
Using the change in occurrence of the 3" storm as a proxy indicator of flood-causing events, an increase of 60-80% is expected by this time period.[3] This increase in risk is likely an underestimate of the increase in risk of larger, more catastrophic events. However, in practice, these larger events are rare and thus, over the timeframe under examination even an 80% increase in risk may or may not manifest itself.

Anticipated magnitude of health burden increase by 2070-2099: **High**
Using the change in occurrence of the 3" storm as a proxy indicator of flood-causing events, an increase of 80-120% is expected by this time period.[3] This increase in risk is an underestimate of the increase in risk of larger, more catastrophic events. However, in practice, these larger events are also more rare and thus, over the timeframe under examination, even an 120% increase in risk may or may not manifest itself.

Current vulnerability: **High**
Tropical Storm Irene highlighted some of Vermont's vulnerability to extreme weather events. Recurring flooding in the state, on almost an annual basis further highlights this vulnerability. Over 4,000 households or businesses are located within the current 100-year floodplain (NFIP 2013). The number of households at risk is probably much greater.

Potential for State-led adaptation: **High**
Several efforts, lead from within the state, are already underway to make Vermont more resilient to extreme weather events. Health efforts can be incorporated into some of these initiatives.

5.1.4 Vector-borne and other infectious disease

Current health burden related to exposure: **High**
There are several hundred cases of Lyme disease every year in Vermont. Also, anaplasmosis cases are rising annually. In 2012 there were two deaths that resulted from Eastern Equine Encephalitis (VDH 2015). West Nile Virus cases also continue to occur sporadically, and there are mosquito pools from Department of Agriculture samples that test positive for the virus every year.

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[3] The Health Department partnered with State Climatologist Lesley-Ann Dupigny-Giroux and post-doctoral researcher Evan Oswald at the University of Vermont to provide Vermont-specific projections of key climate indicators. See chapter 2 for further details.

Likelihood of exposure increase: **High**
While the relationship between climate and vector-borne disease dynamics is highly uncertain, the likelihood of an extended season of mosquito and tick activity is more certain. There is insufficient evidence to demonstrate that the non-mosquito and non-tickborne infectious diseases that were reviewed for this report were climate sensitive.

Anticipated magnitude of health burden increase by 2041-2070: **Medium**
The 15 additional days above freezing by this time period represents a 14% increase in the period of activity. While disease burden may not increase linearly with the lengthening of the season, an increase in disease burden nearing though probably not exceeding 10% seems plausible.

Anticipated magnitude of health burden increase by 2070-2099: **High**
The 42 additional days of mosquito and tick activity represent an increase in season length of 38%. While disease burden may not increase linearly with the lengthening of the season, an increase in disease burden of more than 10% seems plausible.

Current vulnerability: **High**
Of the mosquito-borne diseases identified in the initial review, all but two already have competent vectors in Vermont. The two exceptions share common *Aedes* vectors which may spread northwards over time. Of all the tick-borne diseases listed in the initial review, all but one already have competent vectors in Vermont. The one exception is reliant on the Lone Star tick, which is already present in neighboring states, and which there are reports of in the Vermont Tick Tracker.

Potential for State-led adaptation: **High**
The Health Department is already heavily engaged in addressing mosquito and tick-borne diseases. These efforts can be expanded.

5.1.5 Foodborne and waterborne pathogens

Current health burden related to exposure: **High**
Vermont currently experiences several hundred cases of foodborne and waterborne disease every year.

Likelihood of exposure increase: **High**
Increases in temperature and intense precipitation are very likely. These climate effects will result in increased runoff and create environments more favorable to the proliferation of foodborne and waterborne pathogens as well as chemical contamination of food and water.

Anticipated magnitude of health burden increase by 2041-2070: **Low**
While the environment is likely to become more favorable to pathogens, it is very difficult to ascertain to what extent human exposure will increase, as there are many safeguards already in place that strive to protect the public health. The climate changes expected by the 2041-2070 time period may thus not result in a noticeably increased burden of disease.

Anticipated magnitude of health burden increase by 2070-2099: **Medium**
While the environment is likely to become more favorable to pathogens, it is very difficult to ascertain to what extent human exposure will increase, as there are many safeguards already in place that strive to protect the public health. The climate changes expected by the 2070-2099 will likely be greater than the earlier period, but are still not anticipated to be severe.

Current vulnerability: **High**
There is a high (~40%) proportion of Vermonters using wells and other private water systems, which may not be routinely tested for waterborne pathogens, or adequately treated. Furthermore, all Vermonters are potentially at risk for foodborne diseases if food is handled or prepared improperly. Because of this, vulnerability was listed as *high*, in relation to the other health risks in this section.

Potential for State-led adaptation: **High**
Efforts are currently underway to reduce the burden of foodborne and waterborne disease in Vermont. These efforts can be expanded.

5.1.6 Cyanobacterial blooms

Current health burden related to exposure: **Medium**
There is no robust mechanism to collect data on human disease from exposure to cyanobacterial blooms in Vermont. While severe cases are fairly likely to be reported to the Health Department, the number of individuals that have mild dermal reactions or nausea is unknown. However, cyanobacterial blooms are a substantial obstacle to the full use of Vermont's recreational and potable water resources. This focus area was thus ranked *medium* for current health burden.

Likelihood of exposure increase: **Medium**
Because of the complex mechanics of cyanobacterial bloom formation, it is difficult to tell, with the data and projections currently available, whether the frequency and size of cyanobacterial blooms in Vermont will increase or decrease. However, the popularity of Vermont's beaches is expected to increase with warming summers, which could in itself result in an increase in human exposure even if bloom frequency was to remain constant.

Anticipated magnitude of health burden increase by 2041-2070: **Medium**
Given the uncertainty in both the current health burden and the likelihood of increased exposure, it is difficult to predict the future health burden. However, with swimming likely to increase in popularity as an adaptation to increasing heat, an increase in human exposure of up to 10% appears likely, even if the frequency of blooms was to remain constant.

Anticipated magnitude of health burden increase by 2070-2099: **Medium**
Given the uncertainty in both the current health burden and the likelihood of increased exposure, it is difficult to predict the future health burden. However, with swimming likely to increase in popularity as an adaptation to increasing heat, an increase in human exposure exceeding 10% appears likely, even if the frequency of blooms was to remain constant.

Current vulnerability: **High**

Large numbers of Vermonters make use of recreational waters every summer. Furthermore, several communities rely on drinking water drawn from waters susceptible to blooms.

Potential for State-led adaptation: **High**
Efforts to monitor for and inform the public about cyanobacterial blooms are currently led by State entities and non-governmental partners.

5.1.7 Exposures from mitigation technologies

This exposure was deemed to be outside of the program's scope.

5.1.8 Food insecurity

Current health burden related to exposure: **Medium**
Although levels of food insecurity are fairly high, State and Federal government programs already in place substantially reduce the health burden that results from food insecurity.

Likelihood of exposure increase: **High**
Though the impacts of climate change on Vermont agriculture are less certain, a global increase in food prices driven in part by climate change appears likely (Belanger et al. 2008, Frumkin et al. 2007, Luber et al. 2013). A rise in food costs would in turn increase levels of food insecurity.

Anticipated magnitude of health burden increase by 2041-2070: **Low**
Though it is very difficult to predict what will happen to the global food supply over the coming decades, it is probable that food supply in the United States may be less severely affected than many other regions of the world. This may leave the United States in a better position to limit the rise in food prices and to implement programs to ensure adequate nutrition to those who are food insecure.

Anticipated magnitude of health burden increase by 2070-2099: **Medium**
Though it is very difficult to predict what will happen to the global food supply by the end of the century, it is probable that food supply in the United States may be less severely affected than many other regions of the world. This may leave the United States in a better position to limit the rise in food prices and to implement programs to ensure adequate nutrition to the food insecure, though by the end of the century, this capacity may become further eroded.

Current vulnerability: **High**
An estimated 81,000 Vermonters are currently food insecure.

Potential for State-led adaptation: **Medium**
In the current food insecurity mitigation context, the majority of initiatives are driven by the Federal Government, be it through agricultural policy or through food aid programs such as SNAPS or WIC. However, the State already plays an important role in the implementation of Federal programs.

5.1.9 Population dislocation

Current health burden related to exposure: **Low/unknown**

While gaps in immigrant health need to be addressed, there is little evidence that climate migrant populations account for a substantial part of Vermont's immigrant population and that these populations are in turn receiving substantially inferior care than other Vermonters. There is also little evidence that climate migrants are straining Vermont's health services.

Likelihood of exposure increase: **Low**
While it is likely that climate change will lead to greater population movements, the extent to which these movements will affect the United States and particularly Vermont are less certain.

Anticipated magnitude of health burden increase by 2041-2070: **Low**
The number of resettled refugees entering Vermont is limited based on an assessment of economic carrying capacity. The number of voluntary migrants arriving in Vermont is low compared to major urban areas elsewhere in the country.

Anticipated magnitude of health burden increase by 2070-2099: **Medium**
With worsening climate conditions overseas and increasing sea-level rise, there may be increased immigration pressure and overflow from major urban areas into Vermont. The health needs of new arrivals and any strain they may place on existing resources is however very difficult to estimate.

Current vulnerability: **Medium**
Though difficult to measure, Vermont's vulnerability was listed as medium largely because of characteristics that could draw dislocated populations. These include colder baseline temperatures, an inland location, robust social services, and an active agricultural sector that may present opportunities for agricultural migrants.

Potential for State-led adaptation: **Low**
Vermont is not likely to actively try to ebb the flow of migrants from other states through policies, while influx of migrants from overseas is primarily impacted by Federal policies.

5.1.10 Civil conflict

Current health burden related to exposure: **Low/unknown**
There is no evidence of climate-driven civil conflict in Vermont. Furthermore, while many Vermonters have served overseas in the Armed Forces and have unique health needs, evidence is weak that these deployments were tied to climate change.

Likelihood of exposure increase: **Medium**
The likelihood of *medium* is based on a highly qualitative estimate of the probability of Vermonters being deployed as part of the Armed Forces in response to conflicts driven at least in part by the changing climate. There is no evidence to suggest that over the century, climate-driven conflict would erupt in Vermont itself.

Anticipated magnitude of health burden increase by 2041-2070: **Low**

While scenarios can be envisioned in which worldwide conflict would begin to severely affect a large number of Vermonters, with the information that is presently available, there is no compelling evidence to place the magnitude of the health burden by this period at any other level than *low*.

Anticipated magnitude of health burden increase by 2070-2099: **Low**
While scenarios can be envisioned in which worldwide conflict would begin to severely affect a large number of Vermonters, with the information that is presently available, there is no compelling evidence to place the magnitude of the health burden by this period at any other level than *low*.

Current vulnerability: **Low**
Vermont does not appear to be particularly vulnerable to conflict occurring within the state. While Vermonters do serve in the Armed Forces and may find themselves in harm's way in overseas conflict, the health burden placed on this subset of Vermonters by conflict specifically related to climate change is difficult to estimate.

Potential for State-led adaptation: **Low**
Under the assumption that climate-driven civil conflict will not erupt on a substantial scale in Vermont itself, its impact on Vermonters would largely be defined by foreign policy and the extent to which it would place Vermonters into proximity of overseas conflicts.

5.1.11 Threats to mental health

Current health burden related to exposure: **Medium**
Mental illness is a concern in Vermont, though state rates for depression and suicide are similar or marginally higher than national averages. It is difficult to know what portion of the mental illness in Vermont is related to climate. Between almost annual extreme heat events and flooding events alone, it is likely that climate-related threats to mental health are resulting in some morbidity. However, the lack of data makes it challenging to state that they affect at least 100 Vermonters a year.

Likelihood of exposure increase: **High**
Extreme heat events and severe weather events have both been linked with mental health impacts. Both of these exposures are expected to increase with the changing climate.

Anticipated magnitude of health burden increase by 2041-2070: **High**
With the frequency of extreme heat events expected to double and extreme weather events expected to increase by 60-80% by this timeframe, the mental health impacts of these events may increase by a corresponding proportion.

Anticipated magnitude of health burden increase by 2070-2099: **High**
With the frequency of extreme heat events expected to triple and of extreme weather events expected to increase 80-120% by this timeframe, the mental health impacts of these events are likely to increase by a corresponding proportion.

Current vulnerability: **High**

Mental illness presents a substantial burden in Vermont. In 2010 alone, over 100 Vermonters committed suicide, while thousands of Vermonters suffer from other mental illnesses.

Potential for State-led adaptation: **High**
Efforts to address the mental health impacts of extreme heat, severe weather events and other climate change effects would be led by State agencies, in-state clinicians, and mental health professionals.

5.1.12 Ice safety

Current health burden related to exposure: **Medium**
There were only 2 wintertime drownings between 1999 and 2012.

Likelihood of exposure increase: **Low**
Occurrence of thin ice will very likely become more common. However, lakes will be frozen for less time or may not freeze at all, preventing exposure. Climate projections are inadequate for predicting change in ice storm and freeze/thaw frequency.

Anticipated magnitude of health burden increase by 2041-2070: **Low**
Given both the historic variability of Vermont's climate and the already low number of incidents in that variable context, it is not expected that even a large increase in the occurrence of thin ice would necessarily entrain an increase in the number of serious ice accidents. If ice storms and freeze/thaw cycles occur more frequently, the risk for falls and motor vehicle accidents could increase.

Anticipated magnitude of health burden increase by 2070-2099: **Low**
Given both the historic variability of Vermont's climate and the already low number of incidents in that variable context, it is not expected that even a large increase in the occurrence of thin ice would necessarily result in an increase in the number of serious ice accidents. If ice storms and freeze/thaw cycles occur more frequently, the risk for falls and motor vehicle accidents could increase.

Current vulnerability: **Medium**
Ice fishing, snowmobiling and other winter pastimes that may result in exposure to thin ice remain common in Vermont. Older adults tend to be most susceptible to falls on ice, though all are vulnerable. The high dependence on automobile travel in Vermont increases vulnerability to motor vehicle accidents related to icy road conditions.

Potential for State-led adaptation: **High**
Vulnerable groups are somewhat restricted and may be fairly easy to reach. Frequent icing would likely prompt adaptation in de-icing methods by the Vermont Agency of Transportation (VTRANS), businesses, and residents.

5.1.13 Sea-level rise

Not applicable to Vermont.

5.1.14 Stratospheric ozone depletion

Outside of the program scope.

5.2 BRACE Focus Area Selection

Based on the evaluation carried-out in 5.1, each exposure was assigned a numeric score. Each criterion was graded according to the scoring scheme: High = 2, Medium = 1, Low = 0

Each evaluation criterion was weighted equally. Scores for each criterion were summed to give a total score for each exposure. Scoring is summarized in Table 17, with exposures ranked in order of highest to lowest score.

Table 17: Scoring and Ranking of Exposures

Exposure	Current health burden	Certainty of exposure increase	Magnitude of health burden increase by 2041-2070	Magnitude of health burden increase by 2070-2099	Current Vulnerability	Potential for State-led adaptation	Total Score
Extreme heat events	2	2	2	2	2	2	12
Extreme weather events	1	2	2	2	2	2	11
Vector-borne and other infectious pathogens	2	2	1	2	2	2	11
Threats to mental health	1	2	2	2	2	2	11
Air quality impacts	2	1	2	2	2	1	10
Foodborne and waterborne pathogens	2	2	0	1	2	2	9
Harmful algal blooms	1	1	1	1	2	2	8
Food insecurity	1	2	0	1	2	1	7
Ice safety	1	0	0	0	1	2	4
Population dislocation	0	0	0	1	1	0	2
Civil conflict	0	1	0	0	0	0	1
Exposures from mitigation technologies	Outside of Program Scope						
Sea-level rise	Not Applicable to Vermont						
Stratospheric ozone depletion	Outside of Program Scope						

Two focus areas were renamed to highlight the components most relevant in Vermont. *Vector-borne and other infectious diseases* were renamed *mosquito and tick-borne diseases* as the risk is driven by this subset of vector-borne disease threats. Similarly, *harmful algal blooms* were renamed *cyanobacterial blooms* due to Vermont's exclusive concern with these freshwater blooms.

The six focus areas selected for the BRACE process are:

1) Extreme heat events
2) Extreme weather events
3) Mosquito and tick-borne diseases
4) Air quality impacts
5) Foodborne and waterborne pathogens
6) Cyanobacterial blooms

Threats to mental health and *food insecurity* both received relatively high ratings, but there are currently no plans to assess these climate impacts as part of the formal BRACE process in Vermont. For *threats to mental health,* a lack of local data and scientific understanding present major challenges to assessing mental health impacts attributable to climate change in Vermont. For *food insecurity*, much of the expected cause for additional impact will occur at a global scale. Vermont already has programs in place for addressing local food insecurity, and it is unlikely that Vermont can have much impact on the global drivers of food insecurity. Although formal assessments of these topics will not be completed, these topics will be addressed in communications and adaptation plans as much as possible.

5.3 Planned Quantitative Analyses for BRACE Step 2

The second step of the BRACE process calls for quantitative analyses of the focus areas identified in the Climate and Health Profile Report, in order to project future disease burdens. Planned analyses are described below. These analyses are complicated by the complex nature of some of the focus areas as well as by Vermont's small population, which makes statistically significant results more difficult to obtain. The Health Department thus anticipates that some of the analyses below will not yield meaningful results. In such cases, a qualitative discussion of present and future risks will be used to complete the second BRACE step.

5.3.1 Extreme heat events

Three primary sources of health data have been identified for carrying out epidemiologic analyses of extreme heat events. These are:

- Vital records: for total daily mortality, cause-specific mortality, age-specific mortality;
- Early Aberration Reporting System (EARS) – Vermont's syndromic surveillance system, can be used to obtain total daily emergency department visits and cause-specific emergency department visits, including heat-related syndromes;
- Statewide Incident Reporting Network (SIREN) – for heat-related ambulance transports.

Using methods similar to those used by Metzger et al. in New York City and Martel et al. in Quebec, time series analyses of the above datasets combined with daily temperature and relative humidity datasets will be carried-out to identify thresholds and quantify the historic heat-health relationship. This relationship will then be used in conjunction with projected temperatures to estimate future disease burden.

5.3.2 Extreme weather events

Several time series analyses may help elucidate the health impacts of extreme weather events. Health outcomes of interest would include:

- Total daily deaths
- Drownings
- Motor vehicle crashes (fatal and non-fatal)
- Slips and falls
- Power tool injuries
- Asthma or other respiratory outcomes
- Carbon dioxide poisoning

Vital records and the Early Aberration Reporting System (EARS) would be the source of health outcome data. Because of the localized nature of most extreme weather events, it is unlikely that these would generate enough cases for a statistically significant relationship to be detected. However, relationships between rainfall and disaster declarations may provide an alternative. Such an analysis would deepen understanding of what rainfall amounts result in severe damage.

However, even if severe rainfall thresholds are identified, projections of the occurrence of events with rainfall amounts greater than 3” in 24-hours are highly uncertain. Thus rather than provide a disease burden estimate, the analysis will strive to describe best and worst case scenarios.

5.3.3 Mosquito-borne and tick-borne disease

While the Health Department does have data for Lyme, West Nile Virus and Eastern Equine Encephalitis incidence, the spread of these diseases into Vermont is so recent and still so poorly understood that caution must be exercised in drawing conclusions from statistical relationships between these data and climate indicators. However, existing work, particularly by Ogden et al. for deer ticks in Quebec and DeGaetano et al. for *Culex* mosquitos in New York State can be used in describing the link between weather conditions and vector abundance, or at least periods of vector activity. These relationships will then be linked to climate projections to estimate future vector abundance or periods of vector activity. We may attempt to describe historical associations between Lyme disease incidence and meteorological factors. Future disease burden and its relationship to vector abundance and activity will be examined, though this examination will likely be qualitative in nature.

5.3.4 Foodborne and waterborne pathogens

The Health Department collects data on several food and waterborne diseases. Furthermore, the Early Aberration Reporting System (EARS) can identify increases in emergency department visits for gastrointestinal complaints. Regressions of the incidence of these health indicators on daily precipitation and temperature data will be carried out in an attempt to identify rainfall or temperature thresholds associated with increased risk. The future occurrence of thresholds can in turn be drawn from projection data. The four health indicators that see enough cases to have the potential for meaningful results are:

- Giardiasis
- Salmonellosis
- Campylobacteriosis
- ED visits for gastrointestinal complaints

5.3.5 Air quality impacts

A historic relationship between air quality and health outcomes in Vermont may be difficult to quantify due to the small sample size that Vermont’s population affords. Nevertheless, time-series analyses can be carried out in a similar manner to extreme heat, using daily air quality as the independent variable rather than heat. Health datasets would include:

- Vital records: for total daily mortality, cause-specific mortality, age-specific mortality
- Early Aberration Reporting System (EARS) – for total daily emergency department visits and cause-specific emergency department visits, including respiratory and cardiovascular syndromes

Air quality data is available through the Department of Environmental Conservation.

In the event that no statistically significant relationships are found, the relationships developed by other researchers, particularly as input for the development of NAAQS, will be used.

Projections of future air quality impacts will be carried out through a more in-depth review of the literature on projections of air quality impacts with climate change in North America, with a focus on ozone and on wildfire occurrence. Given the level of uncertainty expected to arise in this analysis, an attempt will be made to describe the best-case and worst-case scenarios. However, the DEC is currently partnering with the University of Vermont to develop models of the impacts of climate change on air quality. If these models are completed within the timeframe of the climate and health adaptation grant, they will be incorporated into the BRACE process.

5.3.6 Cyanobacterial blooms

The Health Department has access to monitoring data of cyanobacterial blooms from Lake Champlain and five inland lakes. This dataset could be used in conjunction with daily weather data to attempt to describe a weather and bloom relationship. However, the complexity of lake systems means that this relationship will be difficult to quantify. Lacking data on a historic relationship between climate and cyanobacterial blooms, projections of future bloom frequency during the current BRACE process would be primarily qualitative.

6. Partners and Stakeholders

Unlike some physical infrastructure adaptations, which can be designed in the present to accommodate a long-term future up to a century in advance, the funding and other operational cycles of the health field generally span a few years and are more reactive in nature. Health adaptations must thus be fully integrated into the policies and functioning of the sector's various stakeholders for any long-lasting results to be achieved. The CHPR can serve as a guide for anticipated climate and health impacts in Vermont, but the identification of the detailed impacts and the development of adaptation strategies must be driven by the stakeholders themselves. The focus of Health Department's Climate and Health Adaptation Program would be in facilitating this process and providing direct technical advice or linking stakeholders to appropriate technical resources. The sections below outline an initial list of stakeholders that the Health Department has or plans to invite to join the adaptation effort, though the door will of course remain open for other participants throughout and beyond the BRACE process.

6.1 Extreme Heat Events

- **Department of Disabilities, Aging and Independent Living (DAIL)**
  DAIL's mission is to make Vermont "the best state in which to grow old or to live with a disability ~ with dignity, respect and independence." It pursues this mission through both direct service provision and through partnerships with the private sector and non-governmental groups. DAIL's data and networks will be invaluable in identifying populations vulnerable to heat and in identifying ways to help them prepare for extreme heat or to reach them during an event.
- **Department of Mental Health**

The Department of Mental Health is the lead state entity on mental health issues. In addition to being a valuable repository of mental health data, the Department is well connected to mental health services providers and to community groups active in the mental health arena.

- **Division of Emergency Preparedness, Response, and Injury Prevention (DEPRIP)**
  DEPRIP is integrated into the State's preparedness and emergency response network. In addition to their valuable expertise, they will serve as facilitator in the Climate and Health Adaptation Program's engagement with State-wide, multi-sectorial, multi-actor preparedness and response efforts.
- **Vermont's Schools**
  The Health Department has already built relationships with many of the state's schools through its various programs. These relationships can be leveraged to reach the younger at-risk group that has been identified in the Health Department's epidemiological analyses of extreme heat.

6.2 Air Quality Impacts

- **Vermont Department of Environmental Conservation (DEC): Air Quality and Climate Division**
  Formerly the Division of Air Pollution and Control, the division recently changed its name to reflect its shifting priorities. The Division is already working with academic partners at the University of Vermont to attempt to project the occurrence of stagnation events and to model various aspects of the biomass combustion cycle.
- **University of Vermont/ University Corporation for Atmospheric Research (UCAR)**
  A formal collaboration through UCAR with Vermont's State Climatologist Dr. Lesley-Ann Dupigny-Giroux and postdoctoral fellow Dr. Evan Oswald, both at the University of Vermont, gives the Health Department and adaptation stakeholders access to extensive local climate expertise.
- **Vermont Asthma Program**
  The Vermont Asthma Program is based out of the Health Department and works extensively with clinical and other community partners to improve the quality of life of Vermonters affected by asthma.
- **Timber Lane Allergy and Asthma Associates**
  In addition to being a major allergy and asthma clinical services provider, Timber Lane Allergy and Asthma Associates are also the sole collectors of pollen counts in Vermont. The Health Department hopes to bring Timber Lane into the adaptation process so that they can share their expertise and data in both the effort to project impacts of climate change on those suffering from allergies and asthma and in developing adaptations.

6.3 Extreme Weather Events

- **Institute for Sustainable Communities: the Resilient Vermont Project**
  The resilient Vermont Project strives to draw actionable lessons from the extensive damage caused by Tropical Storm Irene. The Climate and Health Adaptation Program participated in the project starting in the spring of 2013 and will continue to engage with the project to develop a role for the health sector in the area of flooding.
- **Department of Environmental Conservation: Watershed Management Division**
  The Watershed Management Division is actively engaged in applying the lessons learned from Tropical Storm Irene to promote Vermont's resiliency to flooding events. The Health Department is already in contact with the division regarding overlapping interests and goals.

- **Department of Disabilities, Aging and Independent Living (DAIL)**
  DAIL's mission is to make Vermont "the best state in which to grow old or to live with a disability ~ with dignity, respect and independence." It pursues this mission through both direct service provision and through partnerships with the private sector and non-governmental groups. DAIL's data and networks will be invaluable in identifying populations vulnerable to heat and in identifying ways to help them prepare for flooding or other severe weather events and to reach them during an event.
- **Department of Mental Health**
  The Department of Mental Health is the lead state entity on mental health issues. In addition to being a valuable repository of mental health data, the Department is well connected to mental health services providers and to community groups active in the mental health arena.
- **University of Vermont: Department of Psychiatry and Department of Psychology**
  Several mental health professionals at the University of Vermont's Departments of Psychiatry and Psychology have research interests in post-disaster mental health response.
- **Division of Emergency Preparedness, Response, and Injury Prevention (DEPRIP)**
  DEPRIP is integrated into the State's preparedness and emergency response network. In addition to their valuable expertise, they will serve as facilitator in the Climate and Health Adaptation Program's engagement with State-wide, multi-sectorial, multi-actor preparedness and response efforts.

6.4 Mosquito and tick-borne diseases

- **Vermont Agency of Agriculture, Food, and Markets**
  The Agency of Agriculture, Food, and Markets is the lead state entity for vector control. It benefits from the expertise of the State Entomologist Alan Graham. The Agency will be a valuable partner in projecting impacts of climate on vector dynamics and would lead the development of vector control alternatives.
- **Alan Giese – Professor, Lyndon State College**
  Dr. Giese is a wildlife biologist at Lyndon State College. He is currently working with the Climate and Health Adaptation Program to better understand *Borrelia*, *Anaplasma*, and *Babesia* infection prevalence in tick populations across Vermont.
- **Vermont Department of Fish and Wildlife**
  The Vermont Department of Fish and Wildlife interacts with several groups that are vulnerable mosquito and tick-borne diseases.
- **Vermont State Parks**
  Vermont State Parks interact with several groups that are vulnerable mosquito and tick-borne diseases.

6.5 Foodborne and waterborne pathogens

- **Department of Environmental Conservation: Watershed Management Division**
  In addition to being a valuable partner in flood adaptation, the Division also concerns itself with the quality of Vermont's waters.
- **Agency of Agriculture, Food, and Markets**
  The Vermont Agency of Agriculture, Food, and Markets regulates and provide guidance to Vermont's farmers, food processors, and food sellers.
- **Vermont State Parks**

Vermont State Parks tests beaches on their sites for microbial contamination.

- **Farm Health Task Force**
  The Farm Health Task Force educates farm families, health practitioners, agricultural professionals and the general public about the unique health and safety needs of people living and working on Vermont farms.
- **University of Vermont Extension**
  UVM Extension has several researchers interested in the overlap of climate and food quality. The Health Department had already met with Drs. Lynn Blevins and Joshua Faulkner regarding their work in this subject area.

6.6 Cyanobacterial blooms

- **Department of Environmental Conservation: Watershed Management Division**
  In addition to being a valuable partner in flood adaptation, the Division also concerns itself with the quality of Vermont's waters. Angela Shambaugh at the Division has been particularly engaged in Cyanobacterial bloom monitoring efforts.
- **Lake Champlain Committee**
  The Lake Champlain committee has played a major role in cyanobacterial bloom monitoring and education on Lake Champlain.

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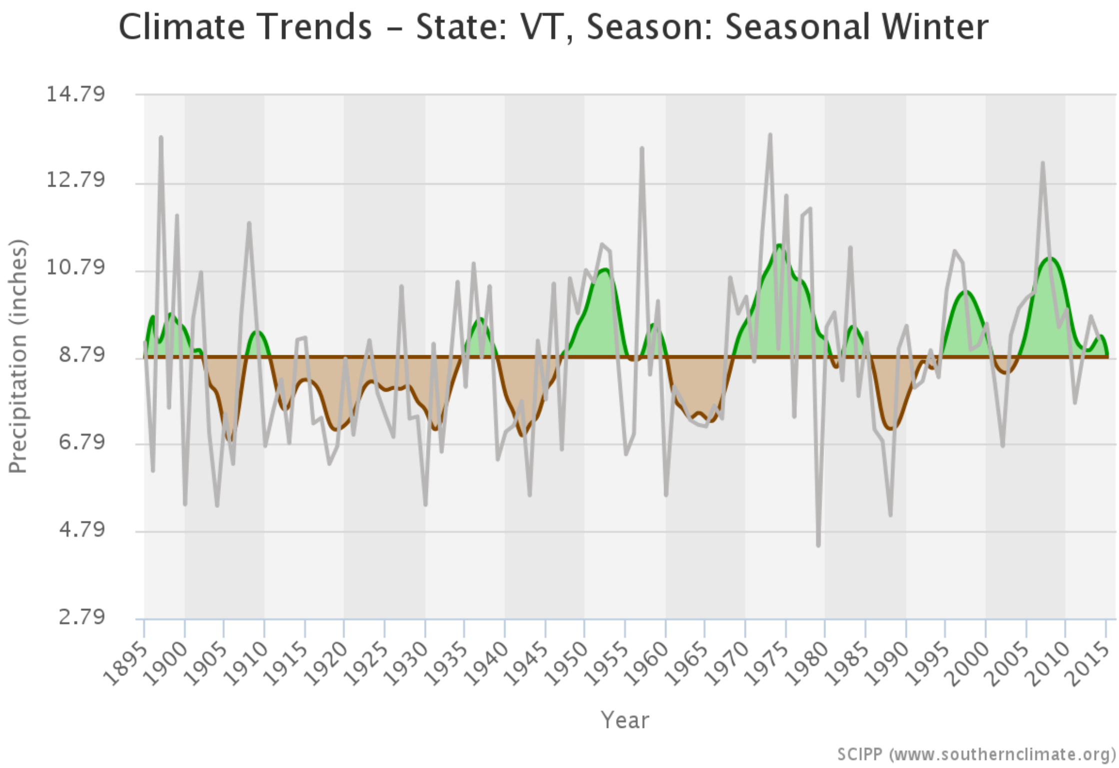
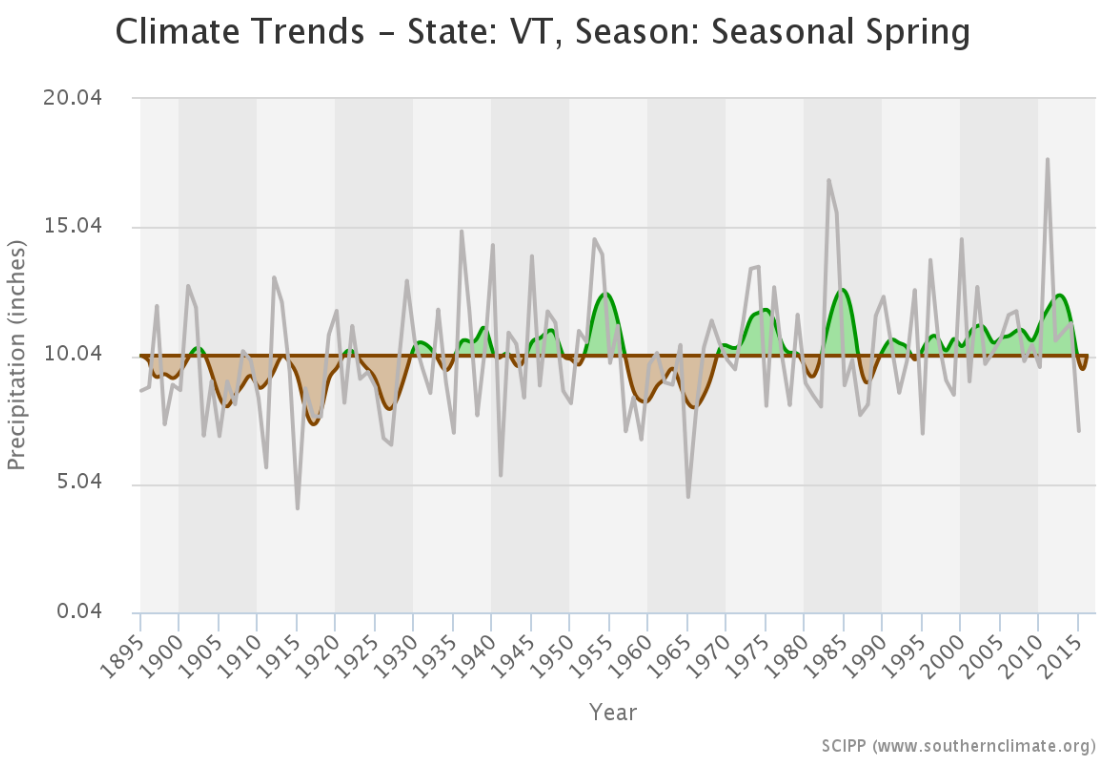
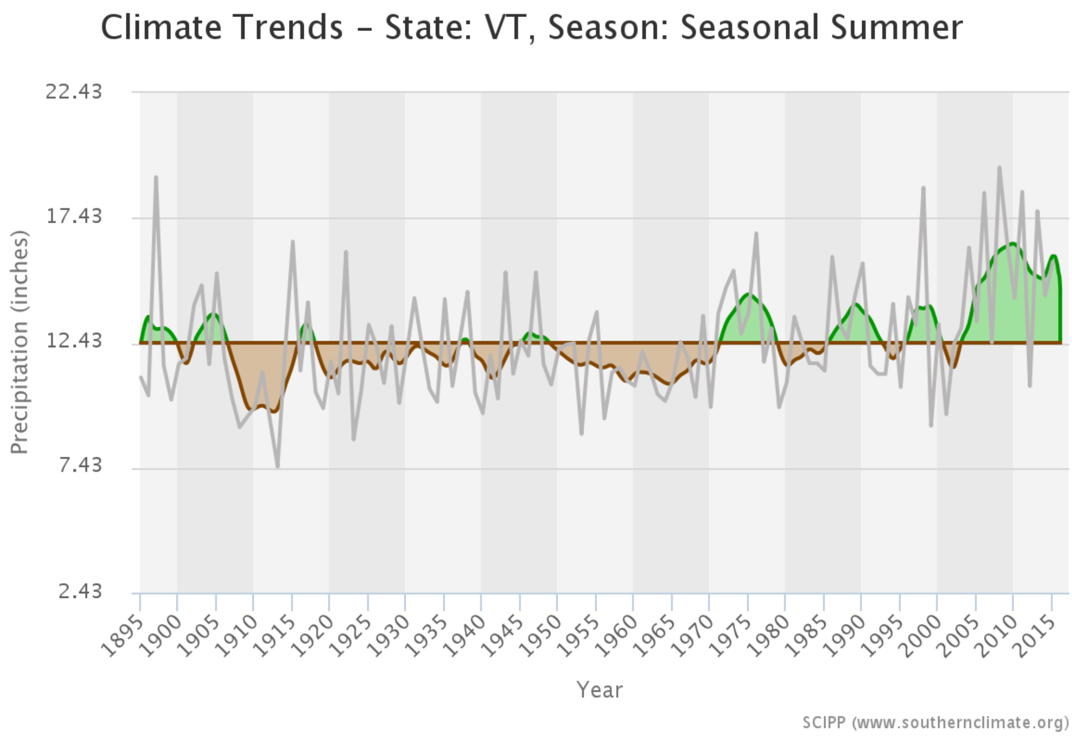
Appendices

Appendix 1: Seasonal Precipitation in Vermont







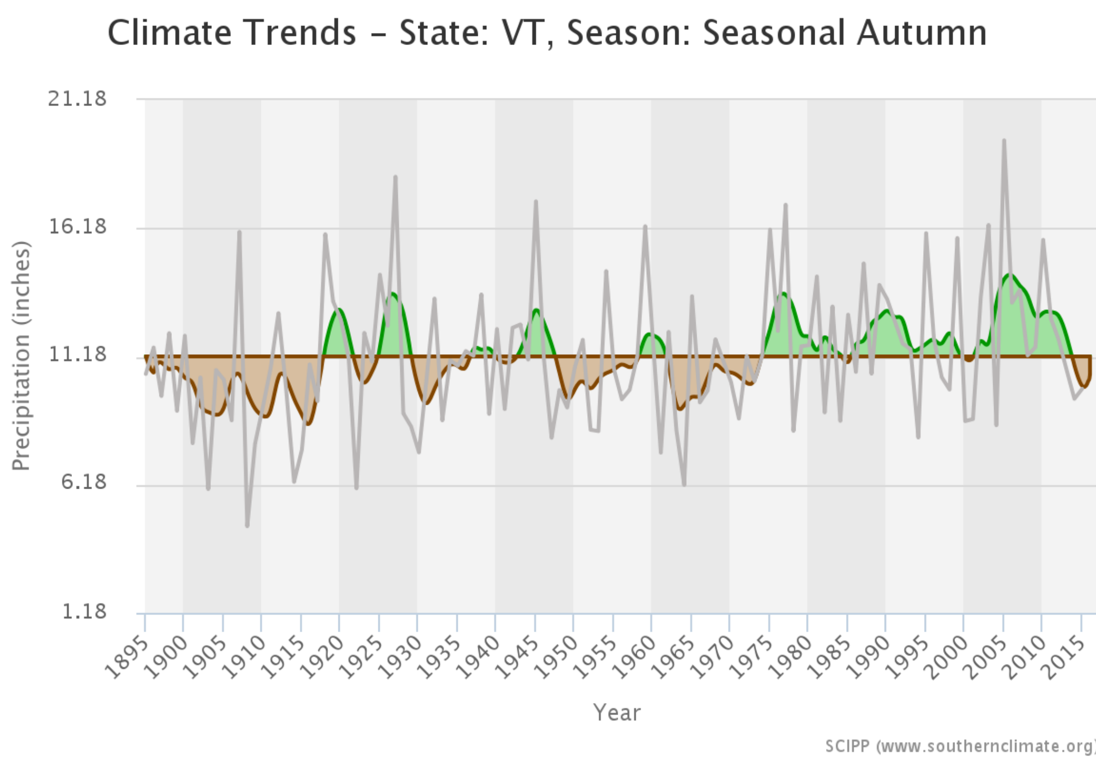
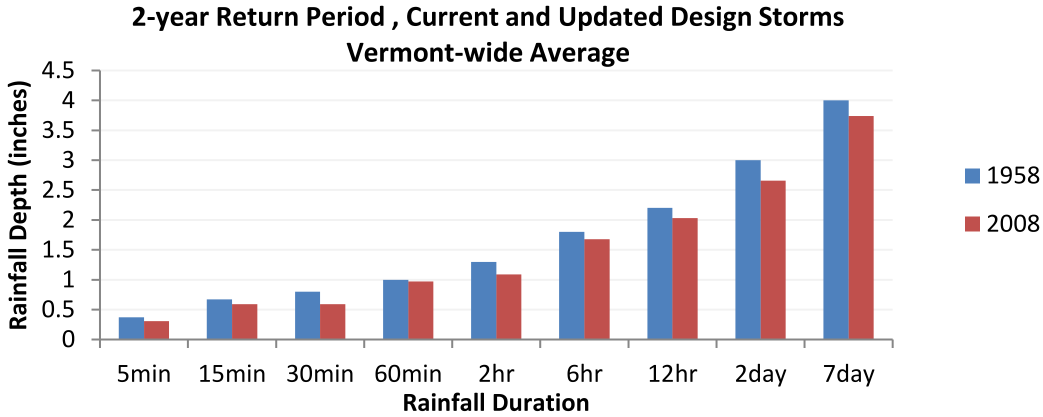


Figure A1.1: Seasonal precipitation in Vermont, 1895 to 2013. Green and brown curves indicate rolling 5-year precipitation average. The centerline represents average precipitation over the time period. Data from NOAA's Nationald Climate Data Center. (LSU 2013).

Appendix 2: 2-year and 100-year Design Storms, Less than and greater than 24-hour duration



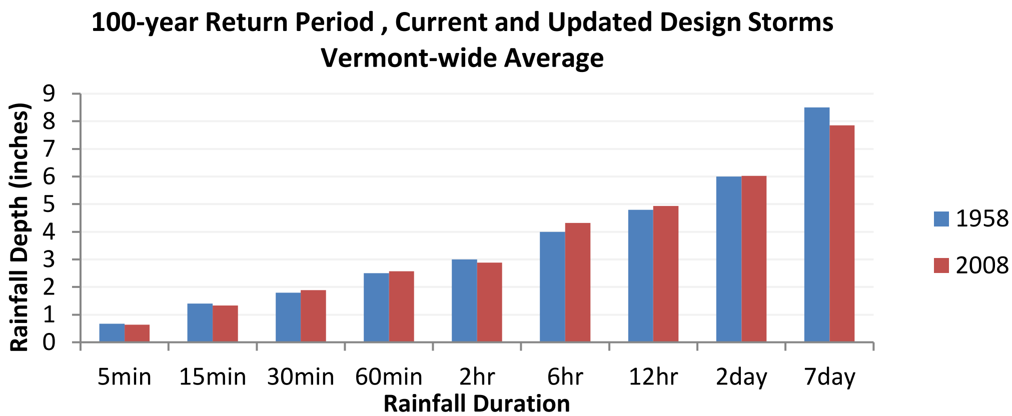


Figure A2.1: 2-year and 100-year Design Storms, Less than and greater than 24-hour duration. These are Vermont-wide averages. There does not appear to be an increasing between the 1958 and 2008 Design Storms. Updated data from Northeast Regional Climate Center (PrecipNet 2013). Current data: for less than 1-hour, Technical Memorandum NWS Hydro 35 (NOAA 1977); for 1-hour to 12-hour, Technical Paper 40; for 2 and 7 day, Technical Paper 49 (NOAA 1964).

Appendix 3: Projection Output for Vermont by Emissions Scenario and Time-slice

Note: VT = statewide average, as used in report

Table A3.1 1981-2010 Baseline

	Mean				*Standard Deviation*			
Climate Region	SE	NE	W	VT	*SE*	*NE*	*W*	*VT*
1. Number of days with rain (pr>0.01") per year	137.9	156.3	145.6	148.9	*11.6*	*15.0*	*15.4*	*14.5*
2. Number of pr>1" precipitation days per year	9.9	7.0	8.5	8.1	*3.1*	*2.8*	*3.1*	*3.0*
3. Number of pr>2" precipitation days per year	1.0	0.6	0.9	0.8	*1.0*	*0.7*	*0.9*	*0.8*
4. Number of pr>3" precipitation days per year	0.2	0.1	0.2	0.1	*0.4*	*0.3*	*0.3*	*0.3*
5. Number of days per year with precipitation exceeding the historical (1981-2010) 50th percentile	68.9	78.1	72.8	74.4	*8.1*	*8.9*	*8.5*	*8.6*
6. Number of days per year with precipitation exceeding the historical (1981-2010) 75th percentile	34.4	39.0	36.4	37.2	*6.2*	*7.0*	*7.0*	*6.8*
7. Number of days per year with precipitation exceeding the historical (1981-2010) 90th percentile	13.8	15.6	14.6	14.9	*3.8*	*4.6*	*4.4*	*4.4*
8. Number of days per year with precipitation exceeding the historical (1981-2010) 99th percentile	1.4	1.6	1.5	1.5	*1.2*	*1.2*	*1.3*	*1.2*
9. Number of days per year with precipitation exceeding the historical (1981-2010) 99.9th percentile	0.1	0.2	0.1	0.1	*0.3*	*0.4*	*0.4*	*0.4*
10. Cumulative precipitation in DJF season	9.8	8.5	8.7	8.8	*1.9*	*1.8*	*1.9*	*1.9*
11. Cumulative precipitation in MAM season	11.2	9.8	10.7	10.4	*3.1*	*2.5*	*2.8*	*2.7*
12. Cumulative precipitation in JJA season	12.0	13.2	13.2	13.0	*3.0*	*3.1*	*3.3*	*3.2*
13. Cumulative precipitation in SON season	12.3	11.9	12.3	12.1	*3.4*	*3.0*	*3.2*	*3.1*
14. Cumulative annual precipitation amount	45.6	43.5	45.0	44.4	*6.1*	*6.2*	*6.6*	*6.3*
15. Ratio of liquid to frozen precipitation	12.9	10.1	14.7	12.3	*10.6*	*6.5*	*10.3*	*8.7*
16. Number of snow days per year	16.5	28.1	19.7	22.8	*4.6*	*7.3*	*5.7*	*6.2*
17. Length of longest dry spell per year	12.7	12.3	13.0	12.6	*2.6*	*2.7*	*3.1*	*2.8*
18. Length of mean dry spell per year	3.3	2.9	3.1	3.1	*0.3*	*0.3*	*0.4*	*0.3*
19. Largest amount of single day precipitation per year	2.4	2.0	2.2	2.2	*0.9*	*0.6*	*0.7*	*0.7*
20. Largest cumulative 3-day precipitation per year	3.4	3.0	3.1	3.1	*1.2*	*1.0*	*1.0*	*1.0*
21. Largest cumulative 5-day precipitation per year	3.9	3.4	3.6	3.6	*1.3*	*1.0*	*1.0*	*1.0*
22. Largest cumulative 10-day precipitation per year	5.0	4.5	4.6	4.6	*1.5*	*1.1*	*1.2*	*1.2*
23. Days per year above daily max temp threshold (87F)	7.4	3.5	5.7	5.1	*5.5*	*3.4*	*4.6*	*4.2*
24. Degree-days per year above daily max temp threshold (87F)	18.5	7.2	14.0	11.9	*17.0*	*8.4*	*13.9*	*12.1*
25. Year-date of first 87 instance/exceedence per year	165.4	175.3	172.0	172.2	*23.6*	*18.7*	*23.2*	*21.3*
26. Number of instances of consecutive days above 87 per year	4.7	1.9	3.6	3.1	*4.5*	*2.5*	*3.7*	*3.3*
27. Length (days) of longest string of consecutive days above 87 per year	2.8	1.7	2.3	2.1	*1.6*	*1.3*	*1.5*	*1.5*
28. Days per year of 64F min temp instances/exceedences per year	5.0	3.4	7.9	5.4	*3.8*	*2.9*	*4.5*	*3.7*

29. Days per year of simultaneous 2 day avg. 64F min temp & 2 day avg. 87F max temp instances/exceedences	1.5	0.7	2.2	1.4	*1.8*	*1.1*	*2.3*	*1.7*
30. Cumulative heating degree days (Tmean under 65F is the traditional threshold) per year	8081.6	8936.2	8242.0	8517.5	*424.7*	*481.6*	*474.8*	*468.5*
31. Cumulative cooling degree days (Tmean over 75F is the traditional threshold)) per year	10.6	4.7	14.5	9.5	*9.9*	*5.4*	*12.6*	*8.9*
32. Days after March 15th that 230 cumulative degree days is reached per year	83.5	88.4	83.4	85.6	*6.6*	*6.6*	*6.7*	*6.6*
33. Cumulative growing degree days	42110.2	39171.5	41347.8	40532.7	*2119.4*	*1957.4*	*2169.4*	*2066.8*
34. Day of year of last freeze	135.2	140.3	134.9	137.3	*9.3*	*9.1*	*9.8*	*9.4*
35. Day of year of first winter freeze	272.2	270.9	273.6	272.2	*10.0*	*10.4*	*9.5*	*10.0*
36. Length of growing season (in days)	136.0	129.6	137.7	133.8	*12.7*	*13.7*	*13.7*	*13.5*
37. Temperature of coldest 3-day average Tmean per year	0.9	-4.9	-1.5	-2.6	*5.6*	*6.1*	*6.2*	*6.0*
38. Days per year Tmin reaches less or equal to 32F	173.9	181.3	167.7	174.8	*8.0*	*8.6*	*9.2*	*8.7*
39. Mean daily maximum temperature in DJF season	31.0	27.1	29.6	28.8	*2.5*	*2.7*	*2.8*	*2.7*
40. Mean daily maximum temperature in MAM season	53.0	50.3	52.1	51.5	*2.3*	*2.3*	*2.4*	*2.4*
41. Mean daily maximum temperature in JJA season	76.6	74.4	75.8	75.3	*1.7*	*1.6*	*1.7*	*1.7*
42. Mean daily maximum temperature in SON season	57.0	54.0	56.1	55.4	*1.6*	*1.6*	*1.7*	*1.6*
43. Mean daily minimum temperature in DJF season	11.2	6.9	10.4	9.0	*3.4*	*3.7*	*3.6*	*3.6*
44. Mean daily minimum temperature in MAM season	30.5	28.2	30.5	29.5	*2.0*	*2.4*	*2.2*	*2.3*
45. Mean daily minimum temperature in JJA season	53.1	52.1	53.8	52.9	*1.7*	*1.6*	*1.6*	*1.6*
46. Mean daily minimum temperature in SON season	35.6	34.5	36.4	35.4	*1.6*	*1.7*	*1.7*	*1.7*
47. Mean annual daily maximum temperature	54.5	51.6	53.5	52.8	*1.2*	*1.2*	*1.3*	*1.2*
48. Mean annual daily minimum temperature	32.7	30.5	32.9	31.8	*1.5*	*1.8*	*1.7*	*1.7*

Table A3.2 2021-2050, B1

	Projected Mean				*Standard Deviation*				Projected Mean Change				*Change Standard Deviation*			
Climate Region	SE	NE	W	VT	*SE*	*NE*	*W*	*VT*	SE	NE	W	VT	*SE*	*NE*	*W*	*VT*
1. Number of days with rain (pr>0.01") per year	137.9	156.5	145.7	149.0	*10.9*	*13.8*	*14.6*	*13.6*	0.0	0.3	0.1	0.2	*-0.7*	*-1.2*	*-0.8*	*-1.0*
2. Number of pr>1" precipitation days per year	10.3	7.4	9.0	8.5	*3.4*	*3.0*	*3.3*	*3.2*	0.4	0.3	0.4	0.4	*0.2*	*0.2*	*0.2*	*0.2*
3. Number of pr>2" precipitation days per year	1.1	0.7	1.0	0.9	*1.1*	*0.8*	*1.0*	*1.0*	0.1	0.1	0.1	0.1	*0.1*	*0.1*	*0.1*	*0.1*
4. Number of pr>3" precipitation days per year	0.3	0.2	0.2	0.2	*0.5*	*0.4*	*0.5*	*0.4*	0.1	0.1	0.1	0.1	*0.1*	*0.1*	*0.1*	*0.1*
5. Number of days per year with precipitation exceeding the historical (1981-2010) 50th percentile	70.6	79.5	74.3	75.9	*8.1*	*8.7*	*8.5*	*8.5*	1.8	1.5	1.5	1.6	*-0.1*	*-0.2*	*0.0*	*-0.1*
6. Number of days per year with precipitation exceeding the historical (1981-2010) 75th percentile	36.2	41.0	38.1	39.0	*6.9*	*7.3*	*7.4*	*7.3*	1.7	2.0	1.8	1.9	*0.7*	*0.4*	*0.4*	*0.4*
7. Number of days per year with precipitation exceeding the historical (1981-2010) 90th percentile	15.0	16.9	15.7	16.1	*4.0*	*4.9*	*4.6*	*4.6*	1.2	1.3	1.1	1.2	*0.2*	*0.3*	*0.2*	*0.2*
8. Number of days per year with precipitation exceeding the historical (1981-2010) 99th percentile	1.6	1.9	1.8	1.8	*1.3*	*1.4*	*1.4*	*1.4*	0.3	0.3	0.3	0.3	*0.1*	*0.2*	*0.2*	*0.2*
9. Number of days per year with precipitation exceeding the historical (1981-2010) 99.9th percentile	0.2	0.3	0.3	0.3	*0.5*	*0.5*	*0.5*	*0.5*	0.1	0.2	0.1	0.1	*0.1*	*0.1*	*0.1*	*0.1*
10. Cumulative precipitation in DJF season	10.2	8.9	9.1	9.2	*1.9*	*1.8*	*1.9*	*1.9*	0.4	0.4	0.4	0.4	*0.0*	*0.0*	*0.1*	*0.0*
11. Cumulative precipitation in MAM season	11.6	10.3	11.1	10.9	*3.2*	*2.4*	*2.8*	*2.7*	0.4	0.5	0.5	0.5	*0.1*	*0.0*	*0.0*	*0.0*
12. Cumulative precipitation in JJA season	12.3	13.3	13.3	13.1	*2.9*	*3.1*	*3.3*	*3.1*	0.2	0.1	0.1	0.1	*-0.1*	*0.0*	*-0.1*	*0.0*
13. Cumulative precipitation in SON season	12.7	12.1	12.7	12.5	*3.9*	*3.2*	*3.6*	*3.5*	0.4	0.2	0.4	0.3	*0.4*	*0.3*	*0.4*	*0.3*
14. Cumulative annual precipitation amount	47.0	44.8	46.4	45.8	*6.6*	*6.5*	*6.9*	*6.6*	1.5	1.3	1.4	1.4	*0.5*	*0.3*	*0.3*	*0.3*
15. Ratio of liquid to frozen precipitation	15.2	11.2	16.6	14.0	*13.0*	*6.9*	*12.0*	*9.9*	2.3	1.2	1.9	1.6	*2.4*	*0.3*	*1.6*	*1.2*
16. Number of snow days per year	14.0	24.5	16.8	19.7	*3.9*	*6.4*	*4.7*	*5.3*	-2.5	-3.7	-2.8	-3.1	*-0.7*	*-0.9*	*-1.0*	*-0.9*

17. Length of longest dry spell per year	13.1	12.5	13.2	12.9	*2.8*	*2.8*	*3.1*	*2.9*	0.4	0.2	0.2	0.3	*0.2*	*0.1*	*0.1*	*0.1*
18. Length of mean dry spell per year	3.3	2.9	3.1	3.1	*0.3*	*0.3*	*0.3*	*0.3*	0.0	0.0	0.0	0.0	*0.0*	*0.0*	*0.0*	*0.0*
19. Largest amount of single day precipitation per year	2.6	2.2	2.4	2.3	*1.2*	*0.8*	*0.8*	*0.9*	0.2	0.2	0.2	0.2	*0.3*	*0.2*	*0.2*	*0.2*
20. Largest cumulative 3-day precipitation per year	3.6	3.2	3.3	3.3	*1.5*	*1.1*	*1.2*	*1.2*	0.2	0.2	0.2	0.2	*0.3*	*0.2*	*0.2*	*0.2*
21. Largest cumulative 5-day precipitation per year	4.1	3.6	3.8	3.8	*1.5*	*1.1*	*1.1*	*1.2*	0.2	0.2	0.2	0.2	*0.3*	*0.1*	*0.2*	*0.2*
22. Largest cumulative 10-day precipitation per year	5.2	4.7	4.9	4.8	*1.8*	*1.3*	*1.4*	*1.4*	0.2	0.2	0.2	0.2	*0.3*	*0.2*	*0.2*	*0.2*
23. Days per year above daily max temp threshold (87F)	13.2	7.7	11.0	10.0	*7.7*	*5.6*	*6.7*	*6.4*	5.8	4.2	5.3	4.9	*2.2*	*2.2*	*2.1*	*2.2*
24. Degree-days per year above daily max temp threshold (87F)	38.6	18.8	32.7	27.6	*32.8*	*18.7*	*28.1*	*24.8*	20.1	11.6	18.7	15.8	*15.8*	*10.4*	*14.2*	*12.8*
25. Year-date of first 87 instance/exceedence per year	156.7	169.5	165.0	165.4	*22.4*	*17.4*	*21.4*	*19.8*	-8.7	-5.9	-7.0	-6.8	*-1.2*	*-1.3*	*-1.9*	*-1.5*
26. Number of instances of consecutive days above 87 per year	9.9	5.3	8.2	7.2	*7.2*	*5.0*	*6.1*	*5.8*	5.2	3.4	4.6	4.2	*2.7*	*2.4*	*2.4*	*2.5*
27. Length (days) of longest string of consecutive days above 87 per year	4.6	3.2	4.0	3.7	*2.6*	*2.1*	*2.4*	*2.3*	1.8	1.4	1.7	1.6	*0.9*	*0.8*	*1.0*	*0.9*
28. Days per year of 64F min temp instances/exceedences per year	9.0	7.0	13.9	9.9	*5.4*	*4.2*	*5.7*	*5.0*	3.9	3.6	6.0	4.5	*1.6*	*1.3*	*1.2*	*1.3*
29. Days per year of simultaneous 2 day avg. 64F min temp & 2 day avg. 87F max temp instances/exceedences	3.8	2.4	5.7	3.9	*3.4*	*2.5*	*4.1*	*3.3*	2.3	1.8	3.5	2.5	*1.6*	*1.4*	*1.7*	*1.6*
30. Cumulative heating degree days (Tmean under 65F is the traditional threshold) per year	7545.7	8351.7	7715.5	7962.9	*340.5*	*398.5*	*398.8*	*387.6*	-536.0	-584.5	-526.5	-554.6	*-84.2*	*-83.1*	*-76.0*	*-80.8*
31. Cumulative cooling degree days (Tmean over 75F is the traditional threshold)) per year	25.1	15.2	36.7	24.9	*21.2*	*13.7*	*25.3*	*19.4*	14.5	10.6	22.2	15.4	*11.3*	*8.4*	*12.7*	*10.5*
32. Days after March 15th that 230 cumulative degree days is reached per year	77.8	82.8	78.0	80.1	*5.3*	*5.3*	*5.5*	*5.4*	-5.7	-5.7	-5.3	-5.6	*-1.3*	*-1.3*	*-1.2*	*-1.2*
33. Cumulative growing degree days	43560.5	40619.1	42812.0	41986.6	*2108.8*	*2021.7*	*2149.4*	*2086.8*	1450.4	1447.6	1464.1	1454.0	*-10.7*	*64.2*	*-20.0*	*20.0*
34. Day of year of last freeze	131.3	136.3	131.3	133.5	*9.0*	*8.4*	*9.3*	*8.9*	-3.9	-4.0	-3.6	-3.8	*-0.3*	*-0.7*	*-0.5*	*-0.5*
35. Day of year of first winter freeze	277.7	276.1	279.3	277.6	*11.5*	*11.8*	*10.6*	*11.3*	5.5	5.1	5.7	5.4	*1.6*	*1.4*	*1.1*	*1.4*
36. Length of growing season (in days)	145.4	138.8	147.0	143.1	*13.3*	*14.1*	*13.8*	*13.8*	9.4	9.1	9.3	9.3	*0.6*	*0.5*	*0.1*	*0.3*
37. Temperature of coldest 3-day average Tmean per year	4.3	-0.8	2.2	1.3	*6.0*	*6.7*	*6.7*	*6.6*	3.4	4.1	3.8	3.8	*0.4*	*0.7*	*0.5*	*0.5*
38. Days per year Tmin reaches less or equal to 32F	164.7	171.5	158.0	165.2	*7.8*	*8.3*	*9.0*	*8.5*	-9.2	-9.8	-9.7	-9.7	*-0.3*	*-0.3*	*-0.2*	*-0.2*

39. Mean daily maximum temperature in DJF season	32.3	28.5	31.0	30.1	*2.2*	*2.4*	*2.4*	*2.4*	1.2	1.4	1.3	1.3	*-0.3*	*-0.3*	*-0.3*	*-0.3*
40. Mean daily maximum temperature in MAM season	54.7	52.1	53.8	53.2	*1.9*	*2.0*	*2.1*	*2.0*	1.7	1.8	1.7	1.8	*-0.3*	*-0.3*	*-0.3*	*-0.3*
41. Mean daily maximum temperature in JJA season	78.4	76.2	77.5	77.1	*1.6*	*1.5*	*1.6*	*1.6*	1.8	1.8	1.7	1.7	*-0.1*	*-0.1*	*-0.1*	*-0.1*
42. Mean daily maximum temperature in SON season	59.0	56.0	58.0	57.3	*1.8*	*1.8*	*2.0*	*1.9*	1.9	2.0	1.9	1.9	*0.2*	*0.2*	*0.2*	*0.2*
43. Mean daily minimum temperature in DJF season	13.3	9.3	12.6	11.3	*3.0*	*3.3*	*3.3*	*3.2*	2.1	2.4	2.2	2.2	*-0.4*	*-0.4*	*-0.4*	*-0.4*
44. Mean daily minimum temperature in MAM season	32.3	30.2	32.4	31.4	*1.7*	*2.1*	*1.9*	*1.9*	1.8	2.0	1.9	1.9	*-0.3*	*-0.3*	*-0.3*	*-0.3*
45. Mean daily minimum temperature in JJA season	54.8	53.7	55.5	54.6	*1.6*	*1.5*	*1.5*	*1.5*	1.7	1.7	1.6	1.7	*-0.1*	*-0.2*	*-0.1*	*-0.1*
46. Mean daily minimum temperature in SON season	37.5	36.5	38.3	37.4	*1.6*	*1.5*	*1.6*	*1.6*	1.9	2.0	2.0	2.0	*-0.1*	*-0.2*	*-0.1*	*-0.1*
47. Mean annual daily maximum temperature	56.2	53.3	55.2	54.5	*1.0*	*1.0*	*1.1*	*1.0*	1.7	1.7	1.7	1.7	*-0.2*	*-0.2*	*-0.2*	*-0.2*
48. Mean annual daily minimum temperature	34.6	32.6	34.8	33.8	*1.3*	*1.5*	*1.5*	*1.5*	1.9	2.0	1.9	2.0	*-0.2*	*-0.2*	*-0.2*	*-0.2*

Table A3.3 2021-2050, A2

	Projected Mean				*Standard Deviation*				Projected Mean Change				*Standard Deviation*			
Climate Region	SE	NE	W	VT	*SE*	*NE*	*W*	*VT*	SE	NE	W	VT	*SE*	*NE*	*W*	*VT*
1. Number of days with rain (pr>0.01") per year	137.2	154.6	144.3	147.5	10.3	13.4	13.6	12.9	-0.7	-1.7	-1.3	-1.4	-1.3	-1.6	-1.9	-1.7
2. Number of pr>1" precipitation days per year	10.3	7.4	8.9	8.5	3.3	3.0	3.2	3.2	0.4	0.3	0.3	0.3	0.1	0.2	0.2	0.2
3. Number of pr>2" precipitation days per year	1.0	0.6	0.9	0.8	0.9	0.7	0.9	0.8	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0
4. Number of pr>3" precipitation days per year	0.2	0.1	0.2	0.2	0.4	0.3	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
5. Number of days per year with precipitation exceeding the historical (1981-2010) 50th percentile	69.9	79.5	73.7	75.6	8.0	8.3	8.1	8.2	1.0	1.5	1.0	1.2	-0.2	-0.6	-0.4	-0.4
6. Number of days per year with precipitation exceeding the historical (1981-2010) 75th percentile	35.5	40.6	37.7	38.5	5.8	7.1	6.5	6.7	1.0	1.5	1.3	1.3	-0.4	0.1	-0.5	-0.2
7. Number of days per year with precipitation exceeding the historical (1981-2010) 90th percentile	14.4	16.5	15.5	15.7	3.6	4.9	4.6	4.6	0.6	0.9	0.9	0.8	-0.2	0.3	0.2	0.2
8. Number of days per year with precipitation exceeding the historical (1981-2010) 99th percentile	1.6	1.9	1.8	1.8	1.1	1.4	1.3	1.3	0.2	0.3	0.3	0.3	0.0	0.2	0.1	0.1
9. Number of days per year with precipitation exceeding the historical (1981-2010) 99.9th percentile	0.1	0.2	0.2	0.2	0.3	0.4	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10. Cumulative precipitation in DJF season	10.4	9.1	9.3	9.4	2.2	2.1	2.3	2.2	0.6	0.6	0.6	0.6	0.3	0.3	0.4	0.3
11. Cumulative precipitation in MAM season	11.5	10.3	11.1	10.8	2.8	2.3	2.7	2.6	0.3	0.5	0.4	0.4	-0.3	-0.1	-0.2	-0.2
12. Cumulative precipitation in JJA season	11.7	12.7	12.7	12.5	2.7	3.0	3.2	3.0	-0.4	-0.4	-0.4	-0.4	-0.3	-0.1	-0.2	-0.2
13. Cumulative precipitation in SON season	12.5	12.1	12.6	12.4	3.7	3.2	3.5	3.4	0.2	0.2	0.3	0.2	0.3	0.2	0.3	0.3
14. Cumulative annual precipitation amount	46.3	44.4	45.9	45.3	5.9	6.2	6.6	6.3	0.8	0.9	0.9	0.9	-0.2	0.0	0.0	0.0
15. Ratio of liquid to frozen precipitation	20.3	13.5	21.7	17.8	22.2	10.5	20.4	16.3	7.4	3.5	7.1	5.5	11.7	4.0	10.1	7.6
16. Number of snow days per year	11.3	21.8	13.9	16.9	3.9	6.6	4.9	5.5	-5.2	-6.4	-5.8	-6.0	-0.8	-0.7	-0.8	-0.7

17. Length of longest dry spell per year	13.1	12.6	13.3	12.9	2.8	2.9	3.0	2.9	0.4	0.3	0.3	0.3	0.2	0.2	0.0	0.1
18. Length of mean dry spell per year	3.3	3.0	3.1	3.1	0.3	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19. Largest amount of single day precipitation per year	2.5	2.2	2.3	2.3	1.0	0.8	0.8	0.8	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
20. Largest cumulative 3-day precipitation per year	3.4	3.1	3.2	3.2	1.3	1.1	1.1	1.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
21. Largest cumulative 5-day precipitation per year	3.9	3.5	3.6	3.6	1.3	1.1	1.1	1.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.1
22. Largest cumulative 10-day precipitation per year	5.0	4.6	4.7	4.7	1.6	1.2	1.2	1.3	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.1
23. Days per year above daily max temp threshold (87F)	14.9	8.4	12.3	11.0	7.2	5.0	6.2	5.9	7.4	4.9	6.6	6.0	1.8	1.7	1.6	1.7
24. Degree-days per year above daily max temp threshold (87F)	43.2	20.5	36.4	30.6	27.4	16.8	24.1	21.5	24.7	13.3	22.4	18.7	10.4	8.4	10.2	9.4
25. Year-date of first 87 instance/exceedence per year	155.9	169.1	164.4	164.9	22.5	18.1	21.4	20.2	-9.5	-6.3	-7.6	-7.3	-1.1	-0.6	-1.8	-1.1
26. Number of instances of consecutive days above 87 per year	11.3	5.7	9.4	8.1	6.6	4.5	5.6	5.3	6.6	3.8	5.8	5.1	2.1	2.0	2.0	2.0
27. Length (days) of longest string of consecutive days above 87 per year	5.0	3.3	4.2	3.9	2.4	2.0	2.2	2.1	2.2	1.6	1.9	1.8	0.8	0.6	0.7	0.7
28. Days per year of 64F min temp instances/exceedences per year	9.6	7.5	15.0	10.6	5.4	4.2	5.5	4.9	4.5	4.1	7.1	5.3	1.5	1.3	1.0	1.2
29. Days per year of simultaneous 2 day avg. 64F min temp & 2 day avg. 87F max temp instances/exceedences	4.2	2.6	6.4	4.3	3.3	2.3	3.8	3.0	2.7	1.9	4.2	2.9	1.4	1.2	1.5	1.4
30. Cumulative heating degree days (Tmean under 65F is the traditional threshold) per year	7419.0	8233.0	7599.3	7843.5	396.9	450.8	448.7	439.9	-662.7	-703.2	-642.7	-674.0	-27.7	-30.9	-26.1	-28.6
31. Cumulative cooling degree days (Tmean over 75F is the traditional threshold)) per year	27.5	16.3	40.1	27.0	18.4	12.5	22.4	17.3	16.8	11.6	25.5	17.5	8.5	7.2	9.8	8.4
32. Days after March 15th that 230 cumulative degree days is reached per year	76.5	81.5	76.9	78.8	6.1	6.2	6.1	6.1	-7.1	-7.0	-6.4	-6.8	-0.5	-0.4	-0.6	-0.5
33. Cumulative growing degree days	44013.1	41049.7	43281.2	42435.1	2129.9	1899.7	2147.1	2034.9	1902.9	1878.2	1933.4	1902.4	10.5	-57.8	-22.2	-32.0
34. Day of year of last freeze	130.2	135.1	130.1	132.3	9.5	9.3	9.6	9.5	-5.0	-5.2	-4.8	-5.0	0.2	0.2	-0.2	0.1
35. Day of year of first winter freeze	279.4	277.8	280.4	279.1	9.7	10.3	9.9	10.0	7.2	6.9	6.9	6.9	-0.2	-0.1	0.4	0.1
36. Length of growing season (in days)	148.2	141.7	149.4	145.8	13.1	14.1	14.1	13.9	12.2	12.1	11.7	12.0	0.4	0.4	0.3	0.4
37. Temperature of coldest 3-day average Tmean per year	4.5	-0.8	2.4	1.4	5.7	6.6	6.5	6.4	3.7	4.1	4.0	4.0	0.1	0.5	0.3	0.3
38. Days per year Tmin reaches less or equal to 32F	162.6	169.8	156.1	163.3	7.9	8.3	9.4	8.6	-11.3	-11.5	-11.6	-11.5	-0.2	-0.3	0.2	-0.1

39. Mean daily maximum temperature in DJF season	32.7	29.0	31.5	30.6	*2.5*	*2.7*	*2.7*	*2.6*	1.7	1.9	1.8	1.8	*-0.1*	*0.0*	*0.0*	*0.0*
40. Mean daily maximum temperature in MAM season	55.4	52.6	54.4	53.8	*2.1*	*2.1*	*2.2*	*2.1*	2.4	2.4	2.3	2.4	*-0.2*	*-0.2*	*-0.2*	*-0.2*
41. Mean daily maximum temperature in JJA season	78.8	76.5	77.9	77.5	*1.5*	*1.4*	*1.5*	*1.5*	2.2	2.1	2.1	2.1	*-0.2*	*-0.2*	*-0.2*	*-0.2*
42. Mean daily maximum temperature in SON season	59.2	56.2	58.2	57.5	*1.7*	*1.7*	*1.8*	*1.7*	2.2	2.2	2.1	2.2	*0.1*	*0.1*	*0.1*	*0.1*
43. Mean daily minimum temperature in DJF season	13.9	10.0	13.2	11.9	*3.4*	*3.7*	*3.7*	*3.7*	2.7	3.0	2.8	2.9	*0.0*	*0.0*	*0.1*	*0.1*
44. Mean daily minimum temperature in MAM season	32.6	30.5	32.7	31.7	*1.8*	*2.1*	*2.0*	*2.0*	2.1	2.3	2.2	2.2	*-0.3*	*-0.3*	*-0.3*	*-0.3*
45. Mean daily minimum temperature in JJA season	55.2	54.1	55.8	54.9	*1.5*	*1.4*	*1.5*	*1.5*	2.0	2.0	2.0	2.0	*-0.2*	*-0.2*	*-0.2*	*-0.2*
46. Mean daily minimum temperature in SON season	37.6	36.6	38.4	37.4	*1.6*	*1.6*	*1.7*	*1.6*	2.0	2.0	2.0	2.0	*0.0*	*-0.1*	*0.0*	*-0.1*
47. Mean annual daily maximum temperature	56.7	53.7	55.6	55.0	*1.1*	*1.2*	*1.2*	*1.2*	2.1	2.2	2.1	2.1	*0.0*	*-0.1*	*0.0*	*0.0*
48. Mean annual daily minimum temperature	34.9	32.9	35.1	34.1	*1.5*	*1.7*	*1.7*	*1.6*	2.3	2.4	2.3	2.3	*-0.1*	*-0.1*	*-0.1*	*-0.1*

Table A3.4 2041-2070, B1

	Projected Mean				*Standard Deviation*				Projected Mean Change				*Standard Deviation*			
Climate Region	SE	NE	W	VT	*SE*	*NE*	*W*	*VT*	SE	NE	W	VT	*SE*	*NE*	*W*	*VT*
1. Number of days with rain (pr>0.01") per year	137.7	156.0	145.4	148.6	*10.2*	*13.3*	*13.8*	*12.9*	-0.2	-0.2	-0.2	-0.2	*-1.4*	*-1.7*	*-1.7*	*-1.6*
2. Number of pr>1" precipitation days per year	10.6	7.7	9.3	8.8	*3.6*	*3.1*	*3.5*	*3.4*	0.7	0.6	0.8	0.7	*0.5*	*0.3*	*0.4*	*0.4*
3. Number of pr>2" precipitation days per year	1.2	0.8	1.1	1.0	*1.2*	*0.9*	*1.1*	*1.0*	0.2	0.2	0.2	0.2	*0.2*	*0.2*	*0.2*	*0.2*
4. Number of pr>3" precipitation days per year	0.3	0.2	0.3	0.2	*0.5*	*0.4*	*0.5*	*0.5*	0.1	0.1	0.1	0.1	*0.1*	*0.1*	*0.1*	*0.1*
5. Number of days per year with precipitation exceeding the historical (1981-2010) 50th percentile	71.4	81.3	75.4	77.2	*7.9*	*8.9*	*8.2*	*8.4*	2.6	3.2	2.6	2.9	*-0.3*	*0.0*	*-0.3*	*-0.2*
6. Number of days per year with precipitation exceeding the historical (1981-2010) 75th percentile	37.0	42.3	39.3	40.2	*6.5*	*7.3*	*7.1*	*7.1*	2.5	3.3	2.9	3.0	*0.3*	*0.3*	*0.1*	*0.2*
7. Number of days per year with precipitation exceeding the historical (1981-2010) 90th percentile	15.8	18.0	16.6	17.1	*4.0*	*4.9*	*4.6*	*4.6*	2.0	2.4	2.0	2.2	*0.2*	*0.3*	*0.2*	*0.2*
8. Number of days per year with precipitation exceeding the historical (1981-2010) 99th percentile	1.9	2.2	2.0	2.0	*1.5*	*1.5*	*1.6*	*1.5*	0.5	0.6	0.5	0.6	*0.3*	*0.3*	*0.3*	*0.3*
9. Number of days per year with precipitation exceeding the historical (1981-2010) 99.9th percentile	0.3	0.4	0.3	0.3	*0.5*	*0.6*	*0.5*	*0.5*	0.1	0.2	0.2	0.2	*0.2*	*0.2*	*0.2*	*0.2*
10. Cumulative precipitation in DJF season	10.7	9.3	9.5	9.7	*1.9*	*1.9*	*2.0*	*1.9*	0.9	0.9	0.8	0.9	*0.0*	*0.1*	*0.1*	*0.1*
11. Cumulative precipitation in MAM season	11.9	10.6	11.4	11.1	*3.3*	*2.5*	*2.9*	*2.8*	0.7	0.7	0.7	0.7	*0.2*	*0.1*	*0.1*	*0.1*
12. Cumulative precipitation in JJA season	12.4	13.4	13.4	13.2	*2.9*	*3.1*	*3.3*	*3.1*	0.3	0.2	0.3	0.3	*-0.1*	*-0.1*	*0.0*	*-0.1*
13. Cumulative precipitation in SON season	12.9	12.6	13.0	12.8	*3.8*	*3.3*	*3.5*	*3.5*	0.5	0.6	0.7	0.6	*0.4*	*0.3*	*0.3*	*0.3*
14. Cumulative annual precipitation amount	47.9	45.9	47.4	46.9	*6.5*	*6.7*	*7.0*	*6.8*	2.4	2.4	2.5	2.4	*0.4*	*0.5*	*0.4*	*0.4*
15. Ratio of liquid to frozen precipitation	22.5	13.3	21.9	18.2	*31.6*	*8.8*	*20.5*	*17.4*	9.6	3.2	7.3	5.9	*21.0*	*2.3*	*10.2*	*8.7*

16. Number of snow days per year	12.6	22.4	15.0	17.8	4.1	6.6	5.0	5.5	-3.9	-5.8	-4.7	-5.0	-0.6	-0.7	-0.7	-0.7
17. Length of longest dry spell per year	13.6	12.8	13.5	13.2	3.1	2.9	3.4	3.1	0.8	0.5	0.6	0.6	0.5	0.2	0.3	0.3
18. Length of mean dry spell per year	3.3	3.0	3.1	3.1	0.3	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19. Largest amount of single day precipitation per year	2.7	2.3	2.4	2.4	1.2	0.9	0.9	1.0	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
20. Largest cumulative 3-day precipitation per year	3.7	3.3	3.4	3.4	1.6	1.3	1.3	1.3	0.3	0.4	0.3	0.3	0.4	0.3	0.3	0.3
21. Largest cumulative 5-day precipitation per year	4.2	3.8	3.9	3.9	1.6	1.2	1.3	1.3	0.3	0.4	0.3	0.3	0.3	0.3	0.3	0.3
22. Largest cumulative 10-day precipitation per year	5.3	4.8	5.0	4.9	1.8	1.3	1.4	1.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
23. Days per year above daily max temp threshold (87F)	17.3	10.6	14.7	13.4	7.9	5.7	6.9	6.5	9.8	7.1	8.9	8.3	2.4	2.3	2.3	2.3
24. Degree-days per year above daily max temp threshold (87F)	51.9	27.1	45.7	38.5	31.4	19.0	28.0	24.6	33.4	19.9	31.7	26.7	14.4	10.7	14.0	12.6
25. Year-date of first 87 instance/exceedence per year	152.8	165.6	161.3	161.6	22.3	17.0	21.6	19.7	-12.6	-9.7	-10.7	-10.6	-1.3	-1.7	-1.6	-1.6
26. Number of instances of consecutive days above 87 per year	13.6	7.8	11.7	10.3	7.3	5.1	6.3	6.0	8.8	5.9	8.1	7.2	2.8	2.6	2.6	2.7
27. Length (days) of longest string of consecutive days above 87 per year	5.6	4.1	5.0	4.7	2.7	2.2	2.6	2.4	2.9	2.4	2.7	2.6	1.1	0.9	1.1	1.0
28. Days per year of 64F min temp instances/exceedences per year	11.7	9.6	17.9	13.0	5.6	4.5	6.0	5.3	6.7	6.2	10.0	7.6	1.8	1.6	1.4	1.6
29. Days per year of simultaneous 2 day avg. 64F min temp & 2 day avg. 87F max temp instances/exceedences	5.8	3.8	8.4	5.8	3.7	2.7	4.2	3.5	4.3	3.2	6.2	4.4	1.8	1.7	1.9	1.8
30. Cumulative heating degree days (Tmean under 65F is the traditional threshold) per year	7235.8	8012.4	7405.7	7639.7	339.6	384.1	394.1	379.2	-845.8	-923.8	-836.4	-877.8	-85.1	-97.6	-80.8	-89.2
31. Cumulative cooling degree days (Tmean over 75F is the traditional threshold)) per year	35.4	22.9	52.6	35.9	20.4	14.0	25.5	19.4	24.8	18.2	38.0	26.5	10.5	8.7	12.9	10.5
32. Days after March 15th that 230 cumulative degree days is reached per year	75.0	80.0	75.2	77.3	6.0	5.8	6.2	6.0	-8.5	-8.4	-8.2	-8.4	-0.6	-0.8	-0.5	-0.7
33. Cumulative growing degree days	44570.0	41679.7	43834.0	43023.7	2156.6	2000.2	2180.6	2097.4	2459.8	2508.2	2486.1	2491.0	37.2	42.8	11.3	30.6
34. Day of year of last freeze	129.0	133.9	128.4	130.9	8.9	8.4	9.2	8.8	-6.1	-6.4	-6.5	-6.4	-0.4	-0.7	-0.6	-0.6
35. Day of year of first winter freeze	279.7	278.3	281.4	279.7	10.2	10.5	9.7	10.2	7.5	7.3	7.9	7.6	0.3	0.1	0.2	0.2
36. Length of growing season (in days)	149.6	143.4	152.0	147.8	12.9	13.5	13.5	13.4	13.6	13.8	14.4	13.9	0.2	-0.2	-0.3	-0.2
37. Temperature of coldest 3-day	5.9	0.9	3.9	3.0	5.9	6.6	6.6	6.5	5.0	5.8	5.5	5.5	0.2	0.6	0.4	0.5

average Tmean per year																
38. Days per year Tmin reaches less or equal to 32F	158.7	165.3	151.8	159.0	*7.6*	*8.2*	*8.8*	*8.3*	-15.2	-16.0	-15.9	-15.8	*-0.5*	*-0.4*	*-0.4*	*-0.4*
39. Mean daily maximum temperature in DJF season	33.3	29.6	32.1	31.2	*2.3*	*2.4*	*2.5*	*2.4*	2.2	2.5	2.4	2.4	*-0.2*	*-0.3*	*-0.3*	*-0.3*
40. Mean daily maximum temperature in MAM season	55.7	53.1	54.8	54.2	*2.1*	*2.1*	*2.2*	*2.1*	2.7	2.8	2.7	2.8	*-0.2*	*-0.2*	*-0.2*	*-0.2*
41. Mean daily maximum temperature in JJA season	79.4	77.2	78.4	78.0	*1.5*	*1.4*	*1.5*	*1.5*	2.7	2.7	2.6	2.7	*-0.2*	*-0.2*	*-0.2*	*-0.2*
42. Mean daily maximum temperature in SON season	60.1	57.1	59.1	58.4	*1.7*	*1.7*	*1.9*	*1.8*	3.1	3.1	3.0	3.0	*0.1*	*0.1*	*0.1*	*0.1*
43. Mean daily minimum temperature in DJF season	14.9	11.2	14.3	13.0	*2.9*	*3.1*	*3.2*	*3.1*	3.8	4.3	3.9	4.0	*-0.5*	*-0.5*	*-0.5*	*-0.5*
44. Mean daily minimum temperature in MAM season	33.2	31.1	33.4	32.4	*1.8*	*2.2*	*2.0*	*2.1*	2.7	3.0	2.8	2.9	*-0.2*	*-0.2*	*-0.2*	*-0.2*
45. Mean daily minimum temperature in JJA season	55.8	54.7	56.4	55.5	*1.6*	*1.5*	*1.5*	*1.5*	2.6	2.6	2.5	2.6	*-0.1*	*-0.1*	*-0.1*	*-0.1*
46. Mean daily minimum temperature in SON season	38.4	37.5	39.2	38.3	*1.5*	*1.5*	*1.6*	*1.5*	2.9	3.0	2.9	2.9	*-0.1*	*-0.2*	*-0.1*	*-0.1*
47. Mean annual daily maximum temperature	57.2	54.4	56.2	55.6	*1.0*	*1.0*	*1.1*	*1.0*	2.7	2.8	2.7	2.7	*-0.2*	*-0.2*	*-0.2*	*-0.2*
48. Mean annual daily minimum temperature	35.6	33.7	35.9	34.9	*1.3*	*1.5*	*1.5*	*1.4*	3.0	3.2	3.0	3.1	*-0.3*	*-0.3*	*-0.2*	*-0.3*

Table A3.5 2041-2070, A2

	Projected Mean				*Standard Deviation*				Projected Mean Change				*Standard Deviation*			
Climate Region	SE	NE	W	VT	*SE*	*NE*	*W*	*VT*	SE	NE	W	VT	*SE*	*NE*	*W*	*VT*
1. Number of days with rain (pr>0.01") per year	136.9	155.0	144.5	147.7	*11.2*	*14.3*	*14.5*	*13.8*	-1.0	-1.3	-1.1	-1.2	*-0.4*	*-0.7*	*-0.9*	*-0.7*
2. Number of pr>1" precipitation days per year	10.8	7.8	9.4	9.0	*3.5*	*3.2*	*3.4*	*3.4*	0.9	0.8	0.9	0.8	*0.4*	*0.4*	*0.4*	*0.4*
3. Number of pr>2" precipitation days per year	1.1	0.7	1.1	0.9	*1.0*	*0.8*	*1.0*	*0.9*	0.1	0.1	0.2	0.1	*0.1*	*0.1*	*0.1*	*0.1*
4. Number of pr>3" precipitation days per year	0.2	0.2	0.2	0.2	*0.5*	*0.4*	*0.4*	*0.4*	0.1	0.1	0.1	0.1	*0.1*	*0.1*	*0.1*	*0.1*
5. Number of days per year with precipitation exceeding the historical (1981-2010) 50th percentile	70.1	79.5	74.1	75.8	*7.8*	*8.3*	*8.1*	*8.2*	1.3	1.5	1.4	1.4	*-0.3*	*-0.6*	*-0.4*	*-0.5*
6. Number of days per year with precipitation exceeding the historical (1981-2010) 75th percentile	36.6	41.6	38.8	39.6	*6.5*	*7.4*	*7.1*	*7.1*	2.1	2.5	2.4	2.4	*0.3*	*0.4*	*0.0*	*0.2*
7. Number of days per year with precipitation exceeding the historical (1981-2010) 90th percentile	15.3	17.5	16.5	16.7	*4.0*	*5.1*	*4.9*	*4.8*	1.5	1.9	1.9	1.8	*0.2*	*0.5*	*0.5*	*0.4*
8. Number of days per year with precipitation exceeding the historical (1981-2010) 99th percentile	1.9	2.3	2.2	2.2	*1.4*	*1.6*	*1.6*	*1.5*	0.6	0.7	0.7	0.7	*0.2*	*0.3*	*0.3*	*0.3*
9. Number of days per year with precipitation exceeding the historical (1981-2010) 99.9th percentile	0.2	0.3	0.3	0.3	*0.4*	*0.5*	*0.5*	*0.5*	0.1	0.1	0.1	0.1	*0.1*	*0.1*	*0.1*	*0.1*
10. Cumulative precipitation in DJF season	10.9	9.7	9.9	10.0	*2.3*	*2.3*	*2.5*	*2.4*	1.2	1.2	1.2	1.2	*0.4*	*0.5*	*0.6*	*0.5*
11. Cumulative precipitation in MAM season	11.9	10.6	11.5	11.2	*3.1*	*2.5*	*2.9*	*2.8*	0.6	0.8	0.8	0.8	*0.0*	*0.1*	*0.1*	*0.1*
12. Cumulative precipitation in JJA season	11.8	12.6	12.7	12.5	*3.1*	*3.2*	*3.4*	*3.2*	-0.2	-0.6	-0.5	-0.5	*0.1*	*0.1*	*0.1*	*0.1*
13. Cumulative precipitation in SON season	12.7	12.5	13.0	12.7	*3.8*	*3.3*	*3.6*	*3.5*	0.4	0.5	0.7	0.6	*0.3*	*0.3*	*0.4*	*0.3*
14. Cumulative annual precipitation amount	47.5	45.5	47.2	46.5	*6.7*	*6.8*	*7.3*	*6.9*	1.9	2.0	2.2	2.1	*0.5*	*0.6*	*0.7*	*0.6*
15. Ratio of liquid to frozen precipitation	26.5	16.6	27.7	22.5	*31.4*	*12.4*	*27.0*	*21.3*	13.6	6.5	13.0	10.2	*20.8*	*5.8*	*16.6*	*12.6*
16. Number of snow days per	8.2	17.5	10.2	13.1	*3.4*	*5.9*	*4.4*	*4.9*	-8.3	-10.6	-9.5	-9.8	*-1.2*	*-1.4*	*-1.4*	*-1.3*

year																
17. Length of longest dry spell per year	13.2	12.6	13.3	13.0	2.6	2.9	3.0	2.9	0.5	0.3	0.3	0.3	0.0	0.1	-0.1	0.0
18. Length of mean dry spell per year	3.3	3.0	3.2	3.1	0.3	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19. Largest amount of single day precipitation per year	2.6	2.3	2.4	2.4	1.1	0.8	0.9	0.9	0.2	0.3	0.3	0.3	0.2	0.2	0.2	0.2
20. Largest cumulative 3-day precipitation per year	3.6	3.3	3.3	3.4	1.4	1.1	1.2	1.2	0.2	0.3	0.3	0.3	0.1	0.2	0.2	0.2
21. Largest cumulative 5-day precipitation per year	4.1	3.7	3.8	3.8	1.4	1.1	1.2	1.2	0.2	0.3	0.3	0.3	0.1	0.2	0.2	0.2
22. Largest cumulative 10-day precipitation per year	5.2	4.8	4.9	4.9	1.6	1.3	1.3	1.3	0.2	0.3	0.3	0.3	0.1	0.1	0.1	0.1
23. Days per year above daily max temp threshold (87F)	23.1	15.0	19.9	18.3	10.2	7.8	9.0	8.7	15.7	11.5	14.2	13.2	4.7	4.4	4.4	4.5
24. Degree-days per year above daily max temp threshold (87F)	80.4	46.2	72.7	62.2	45.4	30.7	42.7	37.9	61.9	39.0	58.7	50.4	28.4	22.4	28.8	25.8
25. Year-date of first 87 instance/exceedence per year	147.9	160.6	156.9	156.8	23.0	18.8	22.1	20.8	-17.5	-14.8	-15.1	-15.4	-0.6	0.1	-1.1	-0.5
26. Number of instances of consecutive days above 87 per year	19.3	11.9	16.8	15.1	9.6	7.1	8.5	8.1	14.6	10.0	13.2	12.0	5.2	4.6	4.9	4.8
27. Length (days) of longest string of consecutive days above 87 per year	7.4	5.2	6.4	6.1	3.5	3.0	3.3	3.2	4.7	3.5	4.1	4.0	1.9	1.6	1.8	1.7
28. Days per year of 64F min temp instances/exceedences per year	15.5	13.2	22.6	17.0	7.5	6.2	7.6	7.0	10.5	9.8	14.7	11.6	3.6	3.2	3.1	3.3
29. Days per year of simultaneous 2 day avg. 64F min temp & 2 day avg. 87F max temp instances/exceedences	8.8	6.3	12.2	8.9	5.4	4.1	6.1	5.1	7.3	5.7	10.0	7.5	3.5	3.1	3.7	3.4
30. Cumulative heating degree days (Tmean under 65F is the traditional threshold) per year	6945.2	7699.5	7121.2	7341.1	384.7	445.6	434.0	429.9	-1136.5	-1236.6	-1120.9	-1176.4	-40.0	-36.1	-40.9	-38.5
31. Cumulative cooling degree days (Tmean over 75F is the traditional threshold)) per year	56.3	39.3	79.9	57.1	32.0	24.3	39.5	31.2	45.7	34.6	65.4	47.6	22.1	18.9	26.9	22.3
32. Days after March 15th that 230 cumulative degree days is reached per year	73.0	77.8	73.5	75.3	6.6	6.6	6.7	6.7	-10.5	-10.6	-9.8	-10.3	0.1	0.1	0.0	0.0
33. Cumulative growing degree days	45270.7	42403.8	44574.4	43748.9	2195.7	2026.9	2218.3	2130.4	3160.6	3232.3	3226.5	3216.2	76.2	69.5	48.9	63.6
34. Day of year of last freeze	126.0	131.1	126.0	128.2	9.4	9.2	9.8	9.5	-9.2	-9.2	-8.9	-9.1	0.0	0.1	0.0	0.0
35. Day of year of first winter freeze	282.6	281.4	284.7	282.8	9.8	10.0	9.6	9.8	10.4	10.4	11.2	10.7	-0.2	-0.4	0.1	-0.2

36. Length of growing season (in days)	155.6	149.3	157.7	153.6	*13.1*	*13.9*	*14.2*	*13.9*	19.6	19.7	20.1	19.8	*0.4*	*0.3*	*0.4*	*0.3*
37. Temperature of coldest 3-day average Tmean per year	7.4	2.6	5.6	4.6	*5.5*	*6.4*	*6.3*	*6.2*	6.5	7.5	7.1	7.2	*-0.1*	*0.3*	*0.1*	*0.1*
38. Days per year Tmin reaches less or equal to 32F	154.1	160.6	146.5	154.1	*8.3*	*8.7*	*9.3*	*8.8*	-19.7	-20.7	-21.2	-20.7	*0.2*	*0.1*	*0.1*	*0.1*
39. Mean daily maximum temperature in DJF season	34.3	30.8	33.2	32.3	*2.3*	*2.5*	*2.5*	*2.5*	3.2	3.6	3.6	3.5	*-0.2*	*-0.2*	*-0.2*	*-0.2*
40. Mean daily maximum temperature in MAM season	56.7	54.1	55.8	55.2	*2.2*	*2.2*	*2.3*	*2.3*	3.7	3.8	3.7	3.7	*0.0*	*-0.1*	*-0.1*	*-0.1*
41. Mean daily maximum temperature in JJA season	80.6	78.3	79.5	79.2	*1.8*	*1.7*	*1.8*	*1.8*	4.0	3.8	3.7	3.8	*0.1*	*0.1*	*0.1*	*0.1*
42. Mean daily maximum temperature in SON season	60.8	57.8	59.7	59.1	*1.7*	*1.7*	*1.8*	*1.8*	3.8	3.8	3.7	3.7	*0.1*	*0.1*	*0.1*	*0.1*
43. Mean daily minimum temperature in DJF season	16.5	13.0	15.9	14.8	*3.0*	*3.4*	*3.3*	*3.3*	5.3	6.1	5.5	5.7	*-0.3*	*-0.3*	*-0.3*	*-0.3*
44. Mean daily minimum temperature in MAM season	34.0	32.0	34.2	33.2	*1.7*	*2.0*	*1.9*	*1.9*	3.5	3.9	3.6	3.7	*-0.3*	*-0.4*	*-0.3*	*-0.4*
45. Mean daily minimum temperature in JJA season	56.9	55.8	57.5	56.6	*1.8*	*1.7*	*1.7*	*1.7*	3.7	3.7	3.6	3.7	*0.1*	*0.1*	*0.1*	*0.1*
46. Mean daily minimum temperature in SON season	39.2	38.2	40.0	39.1	*1.7*	*1.7*	*1.7*	*1.7*	3.6	3.7	3.6	3.7	*0.1*	*0.0*	*0.0*	*0.0*
47. Mean annual daily maximum temperature	58.2	55.3	57.2	56.6	*1.2*	*1.2*	*1.3*	*1.2*	3.7	3.8	3.7	3.7	*0.0*	*0.0*	*0.0*	*0.0*
48. Mean annual daily minimum temperature	36.7	34.9	37.0	36.0	*1.5*	*1.8*	*1.7*	*1.7*	4.1	4.4	4.1	4.2	*0.0*	*0.0*	*0.0*	*0.0*

Table A3.6 2070-2099, B1

	Projected Mean				*Standard Deviation*				Projected Mean Change				*Standard Deviation*			
Climate Region	SE	NE	W	VT	*SE*	*NE*	*W*	*VT*	SE	NE	W	VT	*SE*	*NE*	*W*	*VT*
1. Number of days with rain (pr>0.01") per year	138.1	156.2	145.5	148.8	*11.6*	*14.3*	*15.2*	*14.2*	0.2	-0.1	-0.1	0.0	*0.0*	*-0.7*	*-0.2*	*-0.4*
2. Number of pr>1" precipitation days per year	10.7	7.6	9.3	8.8	*3.4*	*3.0*	*3.3*	*3.2*	0.8	0.6	0.8	0.7	*0.2*	*0.2*	*0.2*	*0.2*
3. Number of pr>2" precipitation days per year	1.2	0.8	1.1	1.0	*1.0*	*0.9*	*1.0*	*1.0*	0.2	0.2	0.2	0.2	*0.1*	*0.2*	*0.1*	*0.1*
4. Number of pr>3" precipitation days per year	0.3	0.2	0.3	0.2	*0.5*	*0.4*	*0.5*	*0.5*	0.1	0.1	0.1	0.1	*0.1*	*0.1*	*0.1*	*0.1*
5. Number of days per year with precipitation exceeding the historical (1981-2010) 50th percentile	71.8	81.4	76.1	77.6	*7.9*	*8.8*	*8.5*	*8.5*	2.9	3.3	3.3	3.2	*-0.2*	*-0.1*	*0.0*	*-0.1*
6. Number of days per year with precipitation exceeding the historical (1981-2010) 75th percentile	37.5	42.6	39.9	40.7	*6.8*	*7.5*	*7.5*	*7.4*	3.0	3.6	3.6	3.5	*0.6*	*0.6*	*0.4*	*0.5*
7. Number of days per year with precipitation exceeding the historical (1981-2010) 90th percentile	15.6	17.7	16.6	16.9	*3.7*	*4.9*	*4.6*	*4.6*	1.8	2.1	2.0	2.0	*-0.1*	*0.3*	*0.2*	*0.2*
8. Number of days per year with precipitation exceeding the historical (1981-2010) 99th percentile	1.8	2.0	2.0	2.0	*1.3*	*1.4*	*1.5*	*1.4*	0.4	0.5	0.5	0.5	*0.1*	*0.2*	*0.2*	*0.2*
9. Number of days per year with precipitation exceeding the historical (1981-2010) 99.9th percentile	0.3	0.4	0.3	0.3	*0.4*	*0.5*	*0.5*	*0.5*	0.1	0.2	0.2	0.2	*0.1*	*0.2*	*0.1*	*0.1*
10. Cumulative precipitation in DJF season	12.9	11.3	11.5	11.7	*2.8*	*2.6*	*2.8*	*2.7*	3.1	2.8	2.9	2.9	*0.9*	*0.8*	*0.9*	*0.9*
11. Cumulative precipitation in MAM season	13.9	12.3	13.2	12.9	*3.7*	*3.0*	*3.4*	*3.3*	2.6	2.5	2.5	2.5	*0.6*	*0.6*	*0.6*	*0.6*
12. Cumulative precipitation in JJA season	14.3	15.1	15.2	15.0	*3.2*	*3.4*	*3.6*	*3.4*	2.2	1.9	2.0	2.0	*0.2*	*0.2*	*0.2*	*0.2*
13. Cumulative precipitation in SON season	14.3	14.0	14.6	14.3	*4.0*	*3.5*	*3.7*	*3.7*	2.0	2.1	2.2	2.1	*0.6*	*0.5*	*0.5*	*0.5*
14. Cumulative annual precipitation amount	55.5	52.8	54.6	54.0	*7.3*	*7.4*	*7.8*	*7.6*	9.9	9.3	9.7	9.6	*1.2*	*1.3*	*1.2*	*1.2*
15. Ratio of liquid to frozen precipitation	23.3	14.9	23.2	19.6	*27.1*	*10.1*	*17.8*	*16.2*	10.4	4.9	8.5	7.2	*16.5*	*3.6*	*7.4*	*7.5*
16. Number of snow days per	11.1	20.7	13.6	16.2	*3.6*	*6.4*	*4.9*	*5.3*	-5.4	-7.4	-6.1	-6.6	*-1.0*	*-0.9*	*-0.9*	*-0.9*

year																
17. Length of longest dry spell per year	13.6	12.9	13.6	13.3	*3.3*	*3.2*	*3.6*	*3.4*	0.9	0.5	0.6	0.6	*0.7*	*0.5*	*0.5*	*0.5*
18. Length of mean dry spell per year	3.3	3.0	3.1	3.1	*0.3*	*0.3*	*0.3*	*0.3*	0.0	0.0	0.0	0.0	*0.0*	*0.0*	*0.0*	*0.0*
19. Largest amount of single day precipitation per year	3.1	2.7	2.8	2.8	*1.4*	*1.1*	*1.1*	*1.2*	0.7	0.7	0.6	0.6	*0.5*	*0.5*	*0.4*	*0.5*
20. Largest cumulative 3-day precipitation per year	4.3	3.8	3.9	4.0	*1.8*	*1.5*	*1.4*	*1.5*	0.9	0.9	0.8	0.9	*0.5*	*0.5*	*0.5*	*0.5*
21. Largest cumulative 5-day precipitation per year	4.9	4.4	4.5	4.5	*1.7*	*1.5*	*1.4*	*1.5*	1.0	1.0	0.9	1.0	*0.4*	*0.5*	*0.4*	*0.5*
22. Largest cumulative 10-day precipitation per year	6.1	5.5	5.7	5.7	*1.9*	*1.6*	*1.5*	*1.6*	1.1	1.1	1.0	1.1	*0.4*	*0.4*	*0.3*	*0.4*
23. Days per year above daily max temp threshold (87F)	23.1	15.0	20.0	18.4	*9.0*	*7.0*	*8.1*	*7.8*	15.7	11.5	14.3	13.3	*3.5*	*3.6*	*3.5*	*3.5*
24. Degree-days per year above daily max temp threshold (87F)	76.5	42.5	68.5	58.3	*39.4*	*26.3*	*36.8*	*32.6*	58.0	35.3	54.5	46.5	*22.5*	*17.9*	*22.8*	*20.5*
25. Year-date of first 87 instance/exceedence per year	146.7	159.3	155.7	155.6	*20.6*	*15.6*	*19.9*	*18.2*	-18.8	-16.1	-16.3	-16.7	*-3.0*	*-3.1*	*-3.3*	*-3.2*
26. Number of instances of consecutive days above 87 per year	19.3	11.9	16.8	15.1	*8.4*	*6.6*	*7.5*	*7.3*	14.6	10.0	13.3	12.0	*4.0*	*4.0*	*3.9*	*4.0*
27. Length (days) of longest string of consecutive days above 87 per year	7.4	5.2	6.5	6.1	*3.2*	*2.6*	*3.1*	*2.9*	4.7	3.4	4.2	3.9	*1.6*	*1.3*	*1.6*	*1.5*
28. Days per year of 64F min temp instances/exceedences per year	15.5	13.2	22.7	17.1	*6.7*	*5.5*	*6.6*	*6.1*	10.4	9.8	14.8	11.7	*2.8*	*2.6*	*2.1*	*2.4*
29. Days per year of simultaneous 2 day avg. 64F min temp & 2 day avg. 87F max temp instances/exceedences	8.8	6.3	12.3	8.9	*4.7*	*3.7*	*5.3*	*4.5*	7.3	5.7	10.0	7.5	*2.9*	*2.6*	*3.0*	*2.8*
30. Cumulative heating degree days (Tmean under 65F is the traditional threshold) per year	6973.4	7732.8	7154.4	7373.4	*326.9*	*382.1*	*387.2*	*373.4*	-1108.3	-1203.4	-1087.7	-1144.1	*-97.8*	*-99.5*	*-87.6*	*-95.0*
31. Cumulative cooling degree days (Tmean over 75F is the traditional threshold)) per year	53.7	37.2	77.3	54.7	*27.0*	*20.1*	*33.4*	*26.3*	43.1	32.5	62.8	45.2	*17.1*	*14.8*	*20.8*	*17.4*
32. Days after March 15th that 230 cumulative degree days is reached per year	72.3	77.2	72.8	74.6	*5.9*	*5.6*	*6.3*	*5.9*	-11.2	-11.2	-10.6	-11.0	*-0.7*	*-1.0*	*-0.4*	*-0.7*
33. Cumulative growing degree days	45293.0	42413.9	44559.4	43752.6	*2315.7*	*2123.5*	*2401.8*	*2262.1*	3182.8	3242.4	3211.6	3219.9	*196.3*	*166.0*	*232.4*	*195.3*
34. Day of year of last freeze	126.9	131.5	126.7	128.9	*9.3*	*8.5*	*9.6*	*9.0*	-8.3	-8.8	-8.2	-8.5	*0.0*	*-0.6*	*-0.2*	*-0.4*
35. Day of year of first winter freeze	282.6	281.3	284.4	282.7	*11.1*	*11.0*	*10.9*	*11.0*	10.4	10.3	10.8	10.5	*1.2*	*0.6*	*1.4*	*1.0*

36. Length of growing season (in days)	154.7	148.7	156.6	152.8	*13.3*	*13.6*	*14.6*	*13.9*	18.7	19.1	19.0	19.0	*0.6*	*0.0*	*0.8*	*0.4*
37. Temperature of coldest 3-day average Tmean per year	7.3	2.4	5.4	4.4	*5.6*	*6.3*	*6.4*	*6.2*	6.4	7.3	6.9	7.0	*0.0*	*0.3*	*0.1*	*0.2*
38. Days per year Tmin reaches less or equal to 32F	154.2	160.7	147.3	154.5	*8.4*	*9.1*	*10.0*	*9.3*	-19.6	-20.6	-20.4	-20.4	*0.3*	*0.4*	*0.8*	*0.5*
39. Mean daily maximum temperature in DJF season	34.0	30.4	32.8	32.0	*2.3*	*2.4*	*2.5*	*2.4*	2.9	3.3	3.2	3.2	*-0.2*	*-0.3*	*-0.3*	*-0.3*
40. Mean daily maximum temperature in MAM season	56.7	54.0	55.7	55.2	*2.2*	*2.2*	*2.3*	*2.3*	3.7	3.7	3.6	3.7	*-0.1*	*-0.1*	*-0.1*	*-0.1*
41. Mean daily maximum temperature in JJA season	80.7	78.4	79.6	79.3	*1.4*	*1.4*	*1.5*	*1.4*	4.0	4.0	3.8	3.9	*-0.2*	*-0.2*	*-0.2*	*-0.2*
42. Mean daily maximum temperature in SON season	61.0	58.1	60.0	59.3	*1.8*	*1.9*	*2.0*	*1.9*	4.0	4.0	3.9	4.0	*0.2*	*0.3*	*0.2*	*0.3*
43. Mean daily minimum temperature in DJF season	16.1	12.6	15.5	14.3	*2.9*	*3.2*	*3.2*	*3.1*	5.0	5.6	5.1	5.3	*-0.5*	*-0.5*	*-0.5*	*-0.5*
44. Mean daily minimum temperature in MAM season	33.9	31.9	34.1	33.1	*1.8*	*2.2*	*2.1*	*2.1*	3.4	3.8	3.6	3.6	*-0.2*	*-0.2*	*-0.2*	*-0.2*
45. Mean daily minimum temperature in JJA season	56.9	55.8	57.5	56.6	*1.5*	*1.5*	*1.5*	*1.5*	3.7	3.7	3.6	3.7	*-0.1*	*-0.2*	*-0.1*	*-0.1*
46. Mean daily minimum temperature in SON season	39.3	38.3	40.0	39.1	*1.5*	*1.6*	*1.6*	*1.6*	3.7	3.8	3.7	3.7	*-0.1*	*-0.1*	*-0.1*	*-0.1*
47. Mean annual daily maximum temperature	58.2	55.3	57.1	56.5	*1.0*	*1.0*	*1.1*	*1.1*	3.7	3.8	3.6	3.7	*-0.2*	*-0.2*	*-0.1*	*-0.2*
48. Mean annual daily minimum temperature	36.6	34.7	36.9	35.9	*1.2*	*1.5*	*1.4*	*1.4*	3.9	4.2	4.0	4.1	*-0.3*	*-0.3*	*-0.3*	*-0.3*

Table A3.7 2070-2099, A2

	Projected Mean				*Standard Deviation*				Projected Mean Change				*Change in Standard Deviation*			
Climate Region	SE	NE	W	VT	*SE*	*NE*	*W*	*VT*	SE	NE	W	VT	*SE*	*NE*	*W*	*VT*
1. Number of days with rain (pr>0.01") per year	133.7	152.8	142.3	145.3	*10.6*	*13.6*	*13.8*	*13.1*	-4.1	-3.5	-3.3	-3.5	*-1.0*	*-1.4*	*-1.7*	*-1.4*
2. Number of pr>1" precipitation days per year	11.3	8.4	10.0	9.5	*3.5*	*3.3*	*3.5*	*3.4*	1.4	1.4	1.5	1.4	*0.4*	*0.5*	*0.5*	*0.4*
3. Number of pr>2" precipitation days per year	1.4	0.9	1.2	1.1	*1.2*	*1.0*	*1.2*	*1.1*	0.3	0.3	0.4	0.3	*0.2*	*0.2*	*0.2*	*0.2*
4. Number of pr>3" precipitation days per year	0.4	0.2	0.3	0.3	*0.6*	*0.5*	*0.6*	*0.6*	0.2	0.1	0.2	0.2	*0.2*	*0.2*	*0.2*	*0.2*
5. Number of days per year with precipitation exceeding the historical (1981-2010) 50th percentile	70.6	80.7	75.5	76.9	*8.6*	*8.9*	*8.8*	*8.8*	1.7	2.6	2.7	2.5	*0.4*	*-0.1*	*0.4*	*0.2*
6. Number of days per year with precipitation exceeding the historical (1981-2010) 75th percentile	37.0	42.8	40.2	40.7	*6.6*	*7.8*	*7.3*	*7.4*	2.5	3.8	3.8	3.5	*0.5*	*0.8*	*0.3*	*0.6*
7. Number of days per year with precipitation exceeding the historical (1981-2010) 90th percentile	16.1	18.4	17.4	17.6	*4.1*	*5.2*	*4.9*	*4.9*	2.4	2.8	2.8	2.7	*0.3*	*0.6*	*0.5*	*0.5*
8. Number of days per year with precipitation exceeding the historical (1981-2010) 99th percentile	2.3	2.8	2.6	2.6	*1.4*	*1.7*	*1.6*	*1.6*	0.9	1.2	1.1	1.1	*0.2*	*0.5*	*0.4*	*0.4*
9. Number of days per year with precipitation exceeding the historical (1981-2010) 99.9th percentile	0.4	0.4	0.4	0.4	*0.6*	*0.6*	*0.6*	*0.6*	0.2	0.3	0.3	0.3	*0.2*	*0.2*	*0.2*	*0.2*
10. Cumulative precipitation in DJF season	11.9	10.7	10.9	11.0	*2.5*	*2.5*	*2.6*	*2.5*	2.1	2.2	2.2	2.2	*0.6*	*0.7*	*0.7*	*0.7*
11. Cumulative precipitation in MAM season	12.1	11.1	11.9	11.6	*3.5*	*2.9*	*3.3*	*3.1*	0.9	1.3	1.3	1.2	*0.4*	*0.4*	*0.4*	*0.4*
12. Cumulative precipitation in JJA season	12.0	12.8	12.9	12.7	*3.0*	*3.2*	*3.4*	*3.2*	0.0	-0.4	-0.3	-0.3	*0.0*	*0.1*	*0.0*	*0.0*
13. Cumulative precipitation in SON season	12.4	12.3	12.9	12.5	*4.0*	*3.5*	*3.8*	*3.7*	0.1	0.4	0.6	0.4	*0.5*	*0.5*	*0.6*	*0.6*
14. Cumulative annual precipitation amount	48.5	46.9	48.6	47.8	*7.0*	*7.3*	*7.7*	*7.4*	3.0	3.3	3.7	3.4	*0.9*	*1.2*	*1.1*	*1.1*
15. Ratio of liquid to frozen precipitation	62.3	27.5	56.9	44.7	*108.1*	*28.2*	*85.0*	*63.8*	49.4	17.4	42.2	32.4	*97.5*	*21.7*	*74.6*	*55.1*
16. Number of snow days per year	3.7	11.4	5.1	7.6	*2.6*	*5.7*	*3.7*	*4.4*	-12.8	-16.7	-14.6	-15.2	*-2.0*	*-1.6*	*-2.0*	*-1.8*

17. Length of longest dry spell per year	13.9	13.3	13.9	13.6	3.3	3.4	3.6	3.4	1.2	1.0	1.0	1.0	0.7	0.7	0.5	0.6
18. Length of mean dry spell per year	3.4	3.0	3.2	3.2	0.3	0.3	0.3	0.3	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0
19. Largest amount of single day precipitation per year	2.9	2.5	2.7	2.6	1.3	1.0	1.0	1.0	0.5	0.5	0.5	0.5	0.4	0.3	0.4	0.4
20. Largest cumulative 3-day precipitation per year	3.9	3.5	3.6	3.6	1.7	1.5	1.5	1.5	0.5	0.5	0.5	0.5	0.5	0.6	0.5	0.5
21. Largest cumulative 5-day precipitation per year	4.4	4.0	4.1	4.1	1.7	1.5	1.5	1.6	0.5	0.6	0.5	0.5	0.4	0.6	0.5	0.5
22. Largest cumulative 10-day precipitation per year	5.6	5.0	5.2	5.2	2.0	1.7	1.7	1.8	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5
23. Days per year above daily max temp threshold (87F)	39.4	28.1	34.7	32.7	13.1	10.9	11.8	11.7	31.9	24.6	29.0	27.6	7.6	7.6	7.2	7.4
24. Degree-days per year above daily max temp threshold (87F)	172.4	115.6	162.3	143.2	88.0	72.0	88.6	81.0	153.9	108.4	148.3	131.3	71.0	63.6	74.7	68.9
25. Year-date of first 87 instance/exceedence per year	132.5	146.6	143.5	142.8	21.8	17.3	21.1	19.6	-32.9	-28.8	-28.5	-29.5	-1.8	-1.4	-2.1	-1.7
26. Number of instances of consecutive days above 87 per year	35.4	24.7	31.5	29.2	13.0	11.1	11.7	11.7	30.7	22.8	27.9	26.1	8.5	8.6	8.1	8.4
27. Length (days) of longest string of consecutive days above 87 per year	12.6	9.2	11.0	10.5	6.1	5.0	5.5	5.4	9.8	7.5	8.7	8.4	4.4	3.6	4.0	3.9
28. Days per year of 64F min temp instances/exceedences per year	30.1	26.8	38.8	31.7	9.9	8.8	9.6	9.3	25.1	23.5	30.9	26.4	6.1	5.9	5.0	5.6
29. Days per year of simultaneous 2 day avg. 64F min temp & 2 day avg. 87F max temp instances/exceedences	21.2	16.6	25.4	20.6	8.8	8.0	9.3	8.6	19.7	16.0	23.2	19.2	6.9	7.0	7.0	7.0
30. Cumulative heating degree days (Tmean under 65F is the traditional threshold) per year	6163.4	6850.1	6349.0	6532.0	426.8	497.4	483.3	479.0	-1918.2	-2086.1	-1893.1	-1985.5	2.1	15.8	8.5	10.5
31. Cumulative cooling degree days (Tmean over 75F is the traditional threshold)) per year	139.4	110.6	185.9	142.8	66.5	60.0	80.2	68.5	128.7	105.9	171.3	133.4	56.7	54.7	67.7	59.6
32. Days after March 15th that 230 cumulative degree days is reached per year	63.6	68.8	64.4	66.2	7.4	7.4	7.5	7.4	-19.9	-19.6	-19.0	-19.5	0.8	0.9	0.7	0.8
33. Cumulative growing degree days	47669.3	44876.3	46982.4	46184.3	2090.5	2049.9	2171.4	2103.7	5559.1	5704.8	5634.5	5651.6	-28.9	92.4	2.0	36.9
34. Day of year of last freeze	118.8	123.1	118.7	120.6	9.7	9.4	9.7	9.6	-16.4	-17.2	-16.2	-16.7	0.4	0.3	0.0	0.2
35. Day of year of first winter freeze	292.6	292.0	294.9	293.1	10.4	10.7	10.4	10.5	20.4	21.0	21.3	21.0	0.4	0.3	0.9	0.5
36. Length of growing season (in days)	172.8	167.9	175.1	171.5	14.3	15.0	15.4	15.0	36.8	38.2	37.5	37.7	1.6	1.4	1.7	1.5

37. Temperature of coldest 3-day average Tmean per year	11.6	7.4	10.0	9.2	5.4	6.1	6.1	6.0	10.7	12.3	11.6	11.7	-0.2	0.1	-0.1	-0.1
38. Days per year Tmin reaches less or equal to 32F	137.3	142.8	129.7	136.9	10.2	11.4	11.8	11.3	-36.6	-38.5	-38.0	-38.0	2.1	2.7	2.6	2.6
39. Mean daily maximum temperature in DJF season	36.5	33.2	35.6	34.7	2.5	2.7	2.7	2.7	5.4	6.1	5.9	5.9	0.0	0.0	0.0	0.0
40. Mean daily maximum temperature in MAM season	59.8	57.1	58.8	58.2	2.3	2.3	2.3	2.3	6.8	6.8	6.7	6.7	0.0	-0.1	-0.1	0.0
41. Mean daily maximum temperature in JJA season	83.5	81.1	82.4	82.0	1.7	1.7	1.8	1.7	6.9	6.7	6.6	6.7	0.0	0.0	0.2	0.1
42. Mean daily maximum temperature in SON season	63.9	61.0	62.8	62.2	2.0	2.0	2.1	2.1	6.9	6.9	6.7	6.8	0.4	0.4	0.4	0.4
43. Mean daily minimum temperature in DJF season	20.0	17.0	19.6	18.5	3.3	3.7	3.6	3.6	8.8	10.1	9.1	9.5	-0.1	0.0	-0.1	0.0
44. Mean daily minimum temperature in MAM season	36.8	35.1	37.1	36.2	1.8	2.2	2.0	2.1	6.3	6.9	6.6	6.7	-0.2	-0.2	-0.2	-0.2
45. Mean daily minimum temperature in JJA season	59.9	58.8	60.5	59.6	1.8	1.7	1.8	1.8	6.7	6.7	6.6	6.7	0.1	0.1	0.2	0.1
46. Mean daily minimum temperature in SON season	42.1	41.2	42.8	42.0	2.0	2.0	2.0	2.0	6.5	6.7	6.5	6.6	0.4	0.3	0.3	0.3
47. Mean annual daily maximum temperature	61.0	58.2	60.0	59.4	1.4	1.5	1.5	1.5	6.5	6.6	6.5	6.6	0.2	0.3	0.3	0.3
48. Mean annual daily minimum temperature	39.8	38.1	40.1	39.2	1.7	2.0	1.9	1.9	7.1	7.6	7.2	7.4	0.2	0.2	0.2	0.2