VERMONT CLIMATE ASSESSMENT

Considering Vermont's Future in a Changing Climate

A report by

The Gund Institute for Ecological Economics and

The University of Vermont

2014

Online at: www.VTclimate.org

Recommended Citation

Galford, Gillian L., Ann Hoogenboom, Sam Carlson, Sarah Ford, Julie Nash, Elizabeth Palchak, Sarah Pears, Kristin Underwood, and Daniel V. Baker, Eds, 2014: *Considering Vermont's Future in a Changing Climate: The First Vermont Climate Assessment.* Gund Institute for Ecological Economics, 219 pp.

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Acknowledgements

Vermont Climate Assessment Partners

The Vermont Climate Assessment (VCA) is a product of the Gund Institute for Ecological Economics at the University of Vermont (UVM). We thank UVM's office of Community-University Partnerships and Service Learning (CUPS) for endorsement of the VCA and assistance with the course by supporting Daniel Baker as a service learning teaching assistant. A number of partners were invaluable in the production of this report. We thank the National Climate Assessment for communication and coordination with national-scale reporting on climate change, in particular, Jerry Mellilo and Susan Hassol. In the state of Vermont, we thank the Secretary of Natural Resources, Deb Markowitz, her leadership team and staff who provided invaluable expertise to the project. Many state employees contributed to the review of material presented here and we thank them for their time. We thank the state climatologist, Lesley-Ann Dupigny-Giroux, for input on the VCA concept. Additional thanks to the UVM Extension School in providing assistance networking with stakeholders. Specifically, we thank Doug Lantagne, Terry Bradshaw, and Vern Grubinger. We also thank Ray Allen of Allenholm Farm for access to phenology data used in the agriculture chapter and insights into the apple business. Alan Betts has been an instrumental partner in the writing and critiquing of many parts of the VCA and we gratefully acknowledge his contributions. At the National Weather Service, Andy Nash and Paul Sisson have assisted in writing, reviewing and providing data for the VCA, providing a strong foundation in observational records of Vermont's changing climate. Graphics for the VCA and web design was created by Cara Marquis of Marquis Interactive, we thank Cara for her creative talent. A final thanks to The Gund Institute for providing start-up funds for the project and EPSCoR Research on Adaptation to Climate Change support in funding for graduate support by Ann Hoogenboom.

Community Partners

The Vermont Climate Assessment would also like to recognize and thank our community partners for their support in providing information and contributing to or reviewing various chapters within the full assessment. VCA Community Partners included:

Jens Hilke, Vermont Fish and Wildlife Department, Agency of Natural Resources (ANR), Sandy Wilmot, ANR Forests and Climate Change, Asa Hopkins, Director of Energy Policy and Planning, ANR, Lee Karlson, former ANR employee, Ned Swanberg, Flood Hazard Mapping Coordinator, Rivers Management Program, VTANR DEC, Linda McGinnis, ANR, Terry Bradshaw, UVM Extension, Vern Grubenger, Parker Riehle, President of SkiVermont, Craig Whipple, Director of Vermont State Parks, Gregory Gerdel, Chief of Research and Operations for Vermont Tourism and Marketing, Ken Couture and Dorothy Schnure, Green Mtn. Power, Bill Jordan, Dept. of Public Service, Misha Bailey, Gail Hall, VT Agency of Education, Bill Keeton, Professor Forest Ecology and Forestry, UVM, Jamey Fidel, Vermont Natural Resources Council

Foreword: Secretary of the Vermont Agency of Natural Resources, Deb Markowitz

"I remain baffled as to how anyone . . . can look at the evidence that's before our eyes, look at the scientific data and not have [climate change] be the top priority of everything that we do, not only in government, but in our own personal and private lives."
– Governor Peter Shumlin, 2006

In Vermont, we have experienced first-hand the very real and detrimental impact global climate change is having on our communities, our families and our livelihoods. Since I took office as Secretary of Vermont's Agency of Natural Resources only three years ago Vermont has experienced eight federally declared extreme weather disasters. These disasters included Tropical Storm Irene in 2011, which impacted nearly every town in Vermont, destroying 500 miles of roads and damaging 200 bridges; cutting off entire communities for days. We also saw historic snowstorms, historic flooding of Lake Champlain, widespread damage from the rainiest May on record and a number of more localized extreme weather events.

The economic and human costs of these storms are staggering. We cannot wait for the next Irene, or the next historic blizzard, heat wave, drought or wildfire. We must address the causes of climate change and prepare for its inevitable impacts. We need to plan, and we need to act. But to do that, we need good information.

The Vermont Climate Assessment produced by the Gund Institute for Ecological Economics and the University of Vermont is an important tool for scientists, practitioners and policy makers. It is the first comprehensive report, using data collected from across the state, of the changes in Vermont's climate and the impact of those changes on our lives and livelihoods. The climate assessment underscores that uncertainty remains about the future extent of many of the impacts examined in the report, such as the impacts of earlier winter thaw dates on the hydrologic cycle, and the extent to which climate change will affect the frequency, severity or magnitude of ecological disturbance in Vermont's forests. However, little doubt exists that we will experience change. Just by presenting this scientific information, the assessment makes a powerful and persuasive case for decision makers that we have no choice but to act; both to reduce emissions, and to build our resilience in light of the many uncertainties we face.

Addressing climate change is not easy because of the complexity of the issues, and because of the lack of certainty about the speed and nature of the changes we will face. It is a challenge for decision-makers to plan for the impacts of climate change even as we seek to integrate climate resilience into our built and natural systems.

Vermont has an opportunity to lead this effort. Living in small communities, close to the land, we know first-hand that everything is interconnected; vibrant communities, healthy people, well-balanced ecosystems and a strong economy go hand-in-hand. We see that when ecological systems become unbalanced there is a corresponding detrimental impact on our lives and our pocketbooks. We need look no further than our backyard for evidence that this is so: in places where pollution from storm water runoff has made the waters in Lake Champlain un-swimmable, businesses that rely on visitors to the lake are suffering. Where air quality is poor, increasing numbers of children are experiencing asthma attacks that cause unnecessary suffering and economic hardship as parents miss work and pay thousands of dollars in medical expenses. Where wetlands have been compromised or destroyed, flood damage becomes more severe, impacting lives and seriously impairing already strained budgets. Many of these ecological imbalances are exacerbated by climate change.

It is my hope that the Vermont Climate Assessment is the start of an inclusive, broad based, and sustained process for assessing and communicating scientific knowledge of the impacts, risks, and vulnerabilities associated with a changing climate, to support decision-making in Vermont.

By compiling the best scientific information about the current impact of global climate change on Vermont and its likely future impact, we can begin to envision what Vermont would look like as a collection of resilient communities set in a resilient landscape. In each of our cities, towns and villages we can begin to identify our strengths and vulnerabilities and think creatively about the investments we could make today that will help us survive, and even thrive, in the face of unexpected challenges. With good information we can rethink how we build (or rebuild) our transportation infrastructure; how we get and deliver our energy; where and how we grow our communities and preserve or restore ecosystems; and how we create greater economic opportunities for ourselves and for our neighbors.

The work we are doing to create resilient communities is vitally important. These are changing and challenging times; but one thing we have learned as Vermonters is that with good information we can come together to make a real and positive difference for ourselves and for future generations.

Deb Markowitz, Secretary

VERMONT
AGENCY OF NATURAL RESOURCES

Executive Summary

The Vermont Climate Assessment (*VCA*) paints a vivid picture of a changing climate in Vermont and calls for immediate strategic planning to sustain the social, economic and environmental fabric of our state. The VCA is the first state-scale climate assessment in the country and speaks directly to the impacts of climate change as they pertain to our rural towns, cities and communities, including impacts on Vermont tourism and recreation, agriculture, natural resources and energy.

A Call for Action in Vermont

Climate change is no longer a thing of the future; it is affecting Vermont today. Extreme weather events, such as heavy downpours, have become more frequent and/or intense. Across the state, there have already been significant changes in the length of the frost-free growing season and in the warmth of nighttime temperatures. These, and other changes, are part of the pattern of global climate change, primarily driven by human activity. Vermont is a small contributor to global climate change yet must face the local consequences of climate change by building local capacity and resilience.

Many of the impacts associated with climate change affect livelihoods and ecosystems in Vermont. These impacts are the subject of this report and are significant for all communities, especially those with economic or infrastructure challenges, and for species and habitats facing other external pressures. Some impacts of climate change in Vermont are positive, but the negative impacts remain of serious concern for their economic, social and environmental consequences. Of particular significance are adverse effects to agricultural production, including dairy, fruit and maple syrup, more frequent flooding and heavy downpours, and negative influences on winter recreation industries due to reductions in snow cover. To date, Vermont has begun to pursue public policy that builds resilience within its 256 towns—the success of which is dependent upon sustained action as the memory of Tropical Storm Irene (2011), which caused serious damage in the state, begins to fade. The VCA presents information to aid in preparation for these changes in Vermont's climate (Box 1), highlighting opportunities that provide economic benefits and minimize costs over time, while noting the potential outcomes of inaction.

The VCA addresses three main goals: **1) further scientific understanding of global change trends using local, historical data; 2) develop a deeper understanding of future impacts of climate change, and 3) communicate the current state of knowledge on global change impacts in Vermont, focusing on agricultural production, forests, water resources and recreation industries.** Additionally, the VCA serves to cultivate partnerships with stakeholders while investigating priority topics for research by performing a needs assessment to understand what information is most needed for adaptation and mitigation strategies to deliver Vermont towards a more resilient future.

Box 1. Climate vs. Weather

Weather expresses the day-to-day atmospheric conditions, i.e., "what is the weather like at a specific place and point in time?" For example, weather describes more short-term time frames such as rain, snow, sunshine, blizzards, flooding, ice storms, and so on.

Climate expresses patterns of weather over a longer time horizon, i.e., "what are the atmospheric conditions over a period of months, years or decades?" For example, climate describes the average long-term conditions of snowfall, rainfall, temperature, cloud cover, and so on.

"Climate is what you expect, weather is what you get"

Methods: Making the Vermont Climate Assessment

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The VCA is divided into chapters based on the sectors most important to Vermont in the face of global climate change. Each chapter concludes with confidence ratings around the impacts of climate change in Vermont for their respective key messages. "Very high" confidence rankings have strong evidence (established theory, multiple sources, consistent results, well-document methods, etc.) and high consensus. "High" confidence findings have moderate evidence (several sources, some consistency, methods vary and/or documentation is limited, etc.) and medium consensus. "Medium" confidence findings have suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.) and competing schools of thought. "Low" confidence findings have inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods that are not tested) and a disagreement or lack of opinions among experts. The majority of findings in the VCA have a very high to high confidence level. The confidence ranking tables for each chapter's key messages provides 1) documentation of the process the authors used to come to the conclusions in their key messages; 2) additional information to reviewers about the quality of the information used; and 3) allows traceability to data and resources.). Direct references to the data and literature source of the findings can be found in these tables as well as throughout the text. Historical climate data was supplied by NOAA/National Weather Service with assistance from the Burlington office and Andy Nash, Meterologist-in-Charge (NOAA/NWS). Projections of future climate change are supplied by the Intergovernmental Panel on Climate Change and refer to model ensembles from the Couple Model Intercomparison Project Phase 5 (CMIP5) and represent low to high global emission scenarios and representative concentration pathways (Christensen et al. 2013).

National Coordination on Climate Change

The VCA is partnered with the National Climate Assessment (NCA) to engage producers and users of assessment information across the United States. The VCA is the first state-level climate assessment modeled after the NCA. The NCA is mandated by the US Global Change Research Act of 1990 and now serves as a broad communication tool on climate change and its impacts around the United States. The third National Climate Assessment (NCA) was officially released on May 6, 2014 (Melillo et al. 2014). The VCA mirrors the NCA structure but is tailored toward the sectors most applicable to Vermont environmentally, socially and economically.

While the NCA contains a wealth of information, it provides only high-level summaries. The Northeast regional report does not address the breadth and depth of impacts on economic, social and environmental impacts specific to Vermont. To date, Vermont has had no comprehensive assessment of economic impacts of historical climate variability or analysis of regions or sectors that may be challenged under future climate change scenarios. In fact, no single state in the US has completed a state-level climate assessment providing data similar to the NCA until the VCA.

Climate Change in Vermont: Historical Trends

Rising Temperatures: The evidence of changing climate is clear for Vermont. The state's average temperature has increased by 1.3°F since 1960; 45% of this increase has occurred since 1990. The most recent decade was Vermont's hottest on record. All regions within Vermont are experiencing warming, although the changes in temperature are not uniform. Vermont is likely to see larger temperature increases in winter than in summer.

Increasing Precipitation: In general, precipitation has and will continue to increase, particularly in winter months. Through observations taken since the 1940's, we see that rainfall has increased across Vermont with the greatest increases occurring in the mountainous regions. Average annual precipitation across the state has increased by 5.9 inches since 1960; 48% of this increase has occurred since 1990. Rainfall records show that heavy rainfall events are becoming more common and pose threats of flooding. In August, 2011, heavy rainfall saturated the ground and, as a result, flooding was widespread when additional rains fell with the arrival of Tropical Storm Irene.

Freeze-Thaw Cycles: Warmer seasonal temperatures are resulting in later "first-fall freeze" and earlier "last-spring freeze". The result is a change in growing season days, with freeze period decreasing by 3.9 days per decade and growing season increasing by 3.7 days per decade over the past forty years. This also effects the freeze up and thaw out dates of small lakes and ponds.

Flooding: Impacts of flooding on water quality continues to be a concern in agricultural areas where the historical legacy of fertilizer use decades ago is resulting in high levels of nutrient run-off into rivers and lakes. Large pulses of nutrients are stripped from soils and transported through waterways during large precipitation events. Records across Vermont show that flashy flows are increasingly common in our rivers. These large pulses of water in small river valleys may threaten development located in floodplains. Particularly vulnerable to the effects of floods are mobile home parks, and their low-income residents, that are often located in floodplains and can be catastrophically destroyed by just one to two feet of flood water.

Box 2. Projected vs. Predicted

Projected vs. Predicted: We use the term 'projected' rather than 'predicted', as predict implies a certainty that we do not have for future climate conditions. Projections for future conditions carry levels of uncertainty. Located at the end of each chapter are confidence tables that express the likelihood of our key findings on a scale from low to very high.

Forecasts are based on assumptions that reflect the conditions that are expected to exist. For example, a weather forecast is produced by applying existing knowledge to *project* the state of the atmosphere for a given location.

Climate Change in Vermont: Projected Trends

Warming Temperatures: Temperatures will continue to rise, with the next few decades projected (Box 2) to see another 3° F by 2050 and 5° F (1.7° and 2.8° C, respectively) of warming by late century in most areas at the low emissions scenario. According to the IPCC, the amount of warming by the end of this century is projected to be roughly 2° F to 5.2° F (1.1° C to 2.9° C) under a lower emissions scenario involving substantial reductions in emissions after 2050 ("B1 scenario") or 3.6° F to 9.7° F (2.0° to 5.4° C) for a higher emissions scenario assuming continued increases in emissions ("A2 scenario") (Christensen et al. 2013) . Across the state, historical weather data show that temperatures have been warming twice as fast in winter than in summer. As a result of warmer winters, time that Vermont's rivers and lakes are frozen each winter is decreasing by 7 days per decade. Spring has started 2 to 3 days earlier per decade which has increased the growing season by 3.7 days per decade. Due to warmer temperatures and longer growing seasons, Vermont has already transitioned from hardiness zone 4 to zone 5 from 1990 to 2006.

Increasing Precipitation: Precipitation will continue to increase over the next Century in Vermont, with the largest increases occurring in mountainous regions. In the near-term of the next 25 years, much of this precipitation will fall as snow. As temperatures continue to increase, winter precipitation will shift to rainfall in the next 50 years and beyond.

Weather Extremes: The chances of record-breaking high temperature extremes will continue to increase as the climate continues to change. High nighttime temperatures are increasingly common and have widespread impacts on humans, recreation and energy demand. In winter months, warmer nighttime temperatures threaten snow and ice cover for winter recreation. In summer months, this causes increased demand for cooling. An increase in high-energy electric (lighting) storms is projected to continue particularly threatening infrastructure and transportation systems.

The Jet Stream: Vermont's location allows the jet stream, which varies season by season, to deliver much of its short-term weather systems. Recent "blocking" or quasi-stationary patterns in the jet stream have led to prolonged periods of intense rainfall (e.g., June 2013) or dryspells (e.g., August 2012). Scientists believe reductions in ice cover in the Arctic have changed global temperature gradients, which increases the likelihood of blocking patterns and unseasonably high or low temperatures and/or precipitation.

Economic Impacts of Climate Change in Vermont

Policy: Vermont can play a role in demonstrating systemic change for decreasing greenhouse gas emissions. The Vermont State Government has been taking action towards emissions reduction programs since the beginning of the century. A constituent base that values climate change action across the state generally supports current legislation to advance the state goals of a 50% reduction in greenhouse gas emissions by 2028 and 90% of energy obtained from renewable sources by 2050.

Community Development: As average annual rainfall has increased in recent decades, average annual flows in Vermont rivers have increased. Rural and urban communities around Vermont are at risk of these impacts. Many communities have already been highly impacted and are engaged in processes to respond to climate change related transitions through formal planning. Community's infrastructure systems are highly vulnerable to climate change. This vulnerability is exacerbated by the state's mountainous, rural geography and small rural communities with limitations existing in transportation routes and communication systems.

Energy: The temperature rise in summer and the increased use of air conditioning will outweigh the reduction in energy demand for heating in the winter. Increased risk of major storm events in Vermont will threaten energy infrastructure. In June and July of 2013 alone, 70,000 separate energy outages occurred in Vermont. In Vermont, forecasts to 2030 anticipate peak energy load increasing 0.7% annually due to increased demand for air conditioning. Adaptation through the use of renewable, local energy sources will be critically important as extreme weather events increase and threaten fossil fuel-based energy supplies. Energy efficiency and conservation are key components of Vermont's goal of obtaining 90% renewable energy sources by 2050. Energy policy attempts to leverage behavior change to accomplish energy efficiency goals.

Water resources: Warmer temperatures are leading to earlier thaw dates on Vermont's rivers, lakes and ponds and snowpack in the mountains. Average annual stream flows are shifting and, overall, are expected to continue increasing in coming decades. High flows are already occurring more frequently. Under assumptions of high green-house-gas emissions scenarios, up to an 80% increase in the probability of high stream flows is projected by end of the century. Climate models project more frequent high flow events (and flooding), particularly in the winter months as a greater fraction of winter precipitation will fall as rain or freezing rain rather than snow. While Vermont rivers have sustained higher levels of base flow over recent decades in summer months in contrast to other New England states, climate projections show increased potential for short-term dry spells. Too much and too little water pose threats to agriculture, forests, infrastructure, health, and homes.

Forests: Increased temperatures will lengthen growing seasons and increase suitable range for certain Vermont tree species like oak, hickory, and red maple, but decrease suitable range for cold-tolerant species like spruce and fir. Changes in precipitation cycles (wetter winters and extended dry spells in summers) will place more stress on important tree species such as sugar maple and red spruce, which have already experienced periods of decline in Vermont. Certain models project that by the end of the century, the northeast could be dominated by an oak-hickory forest, with spruce-fir forests being virtually non-existent and maple-beech-birch forests being driven north to Maine. Warmer temperatures will result in earlier bud burst and flowering periods for certain species, making them more susceptible to pests and pathogens. Warming temperatures may threaten plant and animal species in our forests by changing growing conditions that are unfavorable or that encourage invasive species. Forests currently offset almost all of Vermont's greenhouse gas emissions so their shifts or losses will feedback to climate change as well as having economic impacts on recreation and tourism, forestry, and maple industries.

Agriculture: Increasingly variable levels of summer precipitation and/or extreme temperatures may heighten challenges in the agricultural sector. Warmer seasonal temperatures will result in later "first-fall freeze" and earlier "last-spring freeze". This extended growing season can increase overall crop productivity and create new crop opportunities. The potential negative effects include increased stress from weed growth, disease outbreaks and pest infestations. Higher CO_2 in the atmosphere promotes photosynthesis and can potentially fuel the growth of many Vermont plant varietals. For Vermont livestock operations, summer heat stress could lead to slight decreases in livestock productivity. More pronounced climate change impacts come from pasture productivity and other production inputs such as feed costs and energy costs. Variations in seasonal precipitation combined with the increased frequency of high-energy storms could lead to extreme year-to-year weather variations with implications on farm business viability.

Recreation and Tourism: In the short term, increasing precipitation will increase snowfall and preserve Vermont's winter recreation industry. In the long term, as snow cover recedes, there are opportunities for increasing summer tourism earnings that could compensate for winter losses as snowfall turns to rain later this century. Within 30-40 years, average winter temperatures are expected to increase to the point that most winter precipitation will fall as rain, which will result in shorter-lasting snowpack and snowfall, reducing the winter tourism and recreation seasons. However, over the next 25 years, snowfall in mountainous areas may increase with increasing winter precipitation (a climate change "sweet spot"), which would have a positive impact on winter-related recreation and tourism industries. The summer tourism and recreation seasons will lengthen, and increased temperatures combined with higher humidity further south are expected to drive more tourists to Vermont. Increased temperatures will encourage expansion of pest species, reducing the quality of the recreation experience and requiring increased monitoring and treatment. Fall recreational opportunities and tourism will lengthen with the warmer temperatures, creating expanded economic opportunities.

Public Health: Climate change may intensify existing health threats, and new health threats will emerge. Potential public health threats include: heat-related illnesses, intensified air pollution, injury associated with flooding events, increase in freshwater-borne disease, and viral diseases carried by ticks and mosquitos. The elderly, children, the poor, and the sick may be more vulnerable to the range of climate change-related health impacts. Pollen counts are increasing with increased temperatures and precipitation, which will increase the burden of allergens and asthma. Location of residence including those in floodplains and narrow mountain valleys increase risk and vulnerability. Just as some choices can make us more vulnerable, other choices can make us more resilient. Maintaining a robust public health infrastructure will be critical to managing the potential health impacts of climate change.

Transportation and Housing: Climate change and other human modifications of ecosystems and landscapes often increase vulnerability to damage from extreme events and reduce natural capacity to modulate the impacts of such events. Floodplain wetlands in Vermont absorb floodwaters and reduce the effects of high flows on river-margin lands. Maintaining intact floodplains will mitigate the chance of disastrous flooding in our communities. High energy storms can bring tornados or cause large windthrows that damage our transportation infrastructure.

Education: The use of education and outreach is needed to help Vermonters avoid negative and costly climate change impacts through changes in our behavior (e.g., energy usage, infrastructure investments, consumer behavior, etc.). Over the past 15 years the Vermont State Government, and in particular the current Governor's Office, has taken a lead role in promoting education and outreach with respect to climate change. Vermont's institutions of higher education are also very active in conducting research and disseminating knowledge to both the scientific community and the public at large. The study of climate change is only partially, but increasingly, incorporated into K-12 education. Student knowledge of earth science lags behind that of biological and physical science. Combining climate change educational activities with appeals to Vermonters' values, changes in material incentives through policy reforms, and strengthened social norms could induce more pro-environmental behavior and improve economic outcomes in light of climate change.

Cross-Cutting Themes

Turning Vulnerability to Resiliency: Taking action through Adaptation and Mitigation

This report defines ***resiliency*** as the capability of social and or natural systems to respond to and recover from climate change events (Box 3). ***Adaptation*** is the process of adjustments that social ecological systems make in response to changing situations to reduce vulnerability from climate change impacts. Meanwhile, ***mitigation*** refers to a proactive process that moderates climate change disruption through reducing our overall contribution to emissions. These terms and their definitions appear in every chapter. The key messages in all chapters are chiefly summarizations of the vulnerability of a given sector, agriculture for instance, to projected climate impacts. Adaptation is often assessed and summarized as well. For example, in the case of the agriculture sector, there are serious vulnerabilities regarding changing growing seasons, but altering specific farm practices or timing of certain operations are adaptation strategies to address this vulnerability. These actions contribute to the resiliency of a farm.

Adaptation presents new opportunities by taking advantage of specific changes in climate, such as growing new crop varieties due to a longer growing season. Mitigation and adaptation are linked, in that effective mitigation reduces the need for adaptation. Vermont has embraced "resilience" as a way to incorporate adaptation and mitigation in policy, lifestyles, and more. This is an empowering stance on climate change and is an essential part of a comprehensive response strategy.

Box 3. Action in Vermont

Adaptation: In Vermont, adaptation activities include town-level planning for flood resilience.
Mitigation: Investments in the state's renewable energy portfolio mitigate our emissions that contribute to the acceleration of climate change impacts.
Resilience: Examples of resilience include designing new bridges to allow for meandering of rivers, such that during flood stage the rivers can jump their bank without damage to transportation infrastructure.

Weather and Climate Extremes

"Extremes" refers to weather and climate events like hot spells, heavy rains, periods of drought and flooding, and severe storms (Box 4). Impacts expected to have the greatest consequences will be characterized by changes in the frequency, intensity, timing, duration, and spatial extent of extremes particularly arriving as unprecedented events. Most of the scientific literature on extremes uses definitions that fall roughly into two categories (IPCC 2012): those related to the probability of occurrence of a certain type of event, and those related to exceeding a particular threshold.

Box 4. Classifying an Extreme

Extremes might be determined by the number, percentage, or fraction of days in a month, season, or year with maximum (or minimum) temperature above the 90th, 95th, or 99th percentile compared to a reference time period, such as the last four decades. Alternatively, how often a threshold temperature, for example 32°F or 90°F, is exceeded during a given decade. Extremes are also measured based on the average frequency of a given event that exceeds a specific magnitude. Extremes is a broad term and refers to a variety of events that vary in timescale.

Future Steps

As climate change and its impacts are becoming more prevalent, Vermonters face choices. As a result of past emissions of heat-trapping gases, additional climate change with its related impacts is now unavoidable. This is due to the long-lived nature of many of these gases, the amount of heat absorbed and retained by the oceans, and other responses within the climate system. However, beyond the next few decades, the amount of climate change will still largely be determined by choices society makes about emissions. While Vermont does not have a remotely significant effect on global greenhouse emissions, it is in a position to demonstrate the effectiveness of various systemic changes in reducing overall greenhouse gas emissions. Vermont's progressive climate policies, particularly regarding energy and transportation, are largely discussed in the climate policy chapter, the energy chapter, and the brief transportation chapter. Both top-down policies and bottom-up management and decision making will ensure our communities thrive as our climate changes. A system that is truly resilient to climate change will be one that embraces and adopts both mitigation and adaptation strategies—this is the future of Vermont.

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Chapter 1: Our Changing Climate

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Key Messages

- **Global climate is changing now, driven by human activities and amplified by water cycle processes, and this change is apparent across a wide range of observations. Global climate is projected to change over the next Century, although the exact magnitude of climate change will depend primarily on the amount of global greenhouse gas emissions and the response of the climate to these emissions.**
- **Vermont average temperatures have increased 2.7° F since 1941. Since 1960, average temperature has increased 1.6° F, and since 1990, average temperatures increased 0.9° F. The last decade was the warmest on record, with average temperatures increasing by 0.4° F.**
- **Winter severity in Vermont has and will continue to decrease as overnight low temperatures steadily climb. Spring has started 2-3 days earlier per decade, such that the growing season has increased by 3.7 days per decade. Vermont has already transitioned from hardiness zone 3-5 to 4 and 5 only, as a result of warmer winter minimum temperatures.**
- **One effect of rising temperatures is that Vermont's lakes are frozen 7 fewer days per decade. Because the natural climate of Vermont varies across the state, the impacts of human-induced climate change will not be smooth across the state or over time.**
- **Vermont's annual precipitation is increasing by 1.0" per decade since 1941. Some parts of the state have experienced even greater increases, particularly mountainous regions. More winter and spring precipitation is projected for Vermont over this century, initially increasing snowfall but, as temperatures rise, later increasing winter rainfall.**
- **Certain types of extreme weather events have become more intense and frequent in Vermont, including floods, and high-energy storms.**

1. Vermont's Changing Climate

This chapter summarizes how climate is changing in Vermont, why it is changing and what is projected for the future. While the focus is on changes in Vermont, there is a need to a broader geographical context to understand climate change. This is the first attempt to provide a state-wide assessment of climate change for Vermont —and the first statewide assessment completed in the United States. The key messages are presented below with supporting evidence. The discussion of each key message includes a summary of recent trends and outlook for the future.

Figure 1.1 *Ten indicators of a Warming World (Arndt et al. 2010). These indicators show that Earth's climate is warming. White arrows indicate increases trends and black arrows indicate decreasing trends. All the indicators expected to increase (decrease) in a warming world are increasing (decreasing).*

1. 2. Background and Global Context:

Global climate is changing now, driven by human activities and amplified by water cycle processes, and this change is apparent across a wide range of observations. Global climate is projected to change over the next century, although the exact magnitude of climate change will depend primarily on the amount of global greenhouse gas emissions and the response of the climate to these emissions.

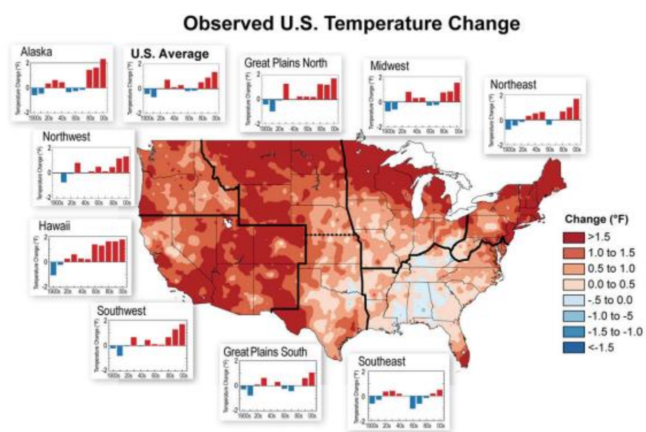


Figure 1.2. *Temperatures changes over the past 20 years (1991-2011) compared to the 1901-1960 average. Bar plots show average temperature changes by decade for 1901-2011 relative to the 1901-1960 average by region (Melillo et al. 2014).*

Climate is defined as the average weather for a place. Changes in weather over time make for changes in climate (Figure 1.1). A large component of global climate change is caused by the Greenhouse Effect, which is a term that describes the increase of heat-trapping gases that lead to increased temperatures. Human activities have led to an increase in the amount of heat-trapping gases, aerosols (small particles) and water vapor in the atmosphere.

Since 1750, the overall effect of human activities on climate has been a warming influence that greatly exceeds known changes in natural processes like solar changes or volcanic eruptions. Global measurements indicate that the earth's surface has been warmed by 0.55° C since the 1970s, with some areas warming more rapidly than others. Likewise, precipitation is changing in amount, intensity, frequency and type of precipitation. Some regions of the world have recorded significantly increased precipitation, including eastern parts of North and South America, northern Europe, and northern and central Asia. Other regions have experienced drying, including the Sahel, southern Africa, the Mediterranean and southern Asia. Globally, the intensity of rainfall events is increasing due to increased water vapor in the atmosphere that evaporates from the oceans as they warm. The polar regions are losing ice rapidly due to warming. Between 1993-2003 it is estimated that melting glaciers, ice caps and ice sheets contributed to sea level rise by 1.2 mm $year^{-1}$. Another cause of sea level rise is the thermal expansion of seawater as it warms.

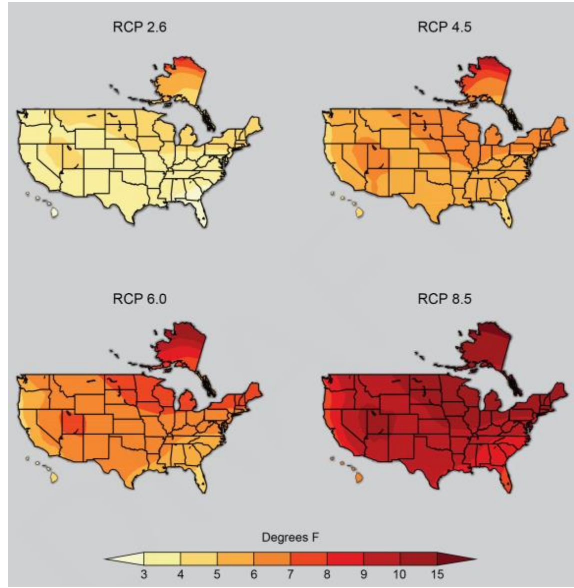
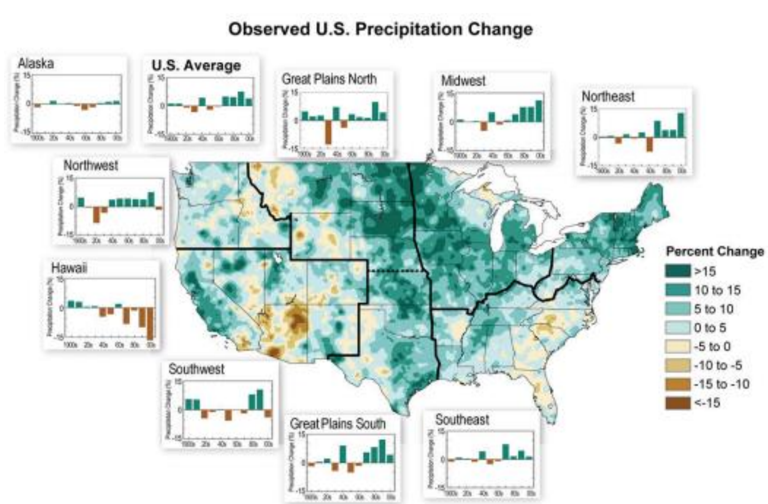


Figure 1.3. *Future temperatures for 2071-2099 based on four scenarios of greenhouse gas emissions. RCP 2.6 assumes rapid reductions in emissions (70% cuts from current levels by 2050) and smaller warming. The RCP 8.5 scenario assumes continued increases in emissions and therefore in warming. RCP 4.5 and 6.0 are intermediate scenarios (Melillo et al. 2014).*

Just as climate varies by region, the impacts of global climate change will vary on local scales due to the uneven distribution of solar heating, individual responses of the atmosphere, oceans and land surface, interactions between these and the physical characteristics of the regions. Within the U.S., every region has experienced warming. The period 2001-2011 was warmer than any previous decade on record (Figure 1.2).

Figure 1.4. *Changes in precipitation over the USA since the 1900s. The colors on the map show annual total precipitation changes (percent) for 1991-2011 compared to the 1901-1960 average, and show wetter conditions in most areas (Melillo et al. 2014)*

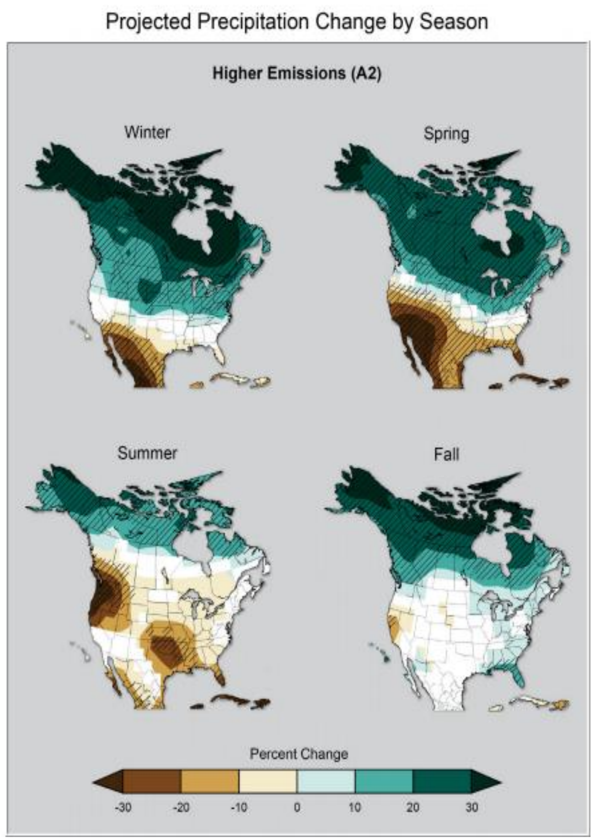


The National Climate Assessment released new climate scenarios in its 2014 publication. All simulated temperature increases show the northeastern U.S. warming by 5°-10° F by the end of the 21st C.

Precipitation is shifting around the world. Most regions of the U.S. show increasing trends in precipitation (Figure 1.4). Increased temperatures increase the evaporation of water. Water vapor in the atmosphere traps heats and further contributes to warming. It also creates more humidity, clouds and rainfall in already wet regions. In the future, computer models estimate that wetter regions will get wetter and drier regions will get drier (Figure 1.5).

Increases in precipitation typically come as heavier storm events. One measure of a heavy-precipitation event is a 2-day precipitation total that is exceeded on average only once in a five-year period, also known as the once-in-five-year event. The occurrence of these extreme precipitation events has become much more common (Figure 1.6; (Melillo et al. 2014). Additionally, the number of high-energy storms, such as category 4 and 5 hurricanes have increased roughly 80% over the last Century (Melillo et al. 2014).

Figure 1.5. *Projected percent change in seasonal precipitation for 2070-2099 (compared to the period 1901-1960) under an emissions scenario that assumes continued increases in emissions (A2). Teal indicates precipitation increases, and brown, decreases. Hatched areas indicate confidence that the projected changes are large and are consistently wetter or drier. White areas indicate confidence that the changes are small. (Melillo et al. 2014)*



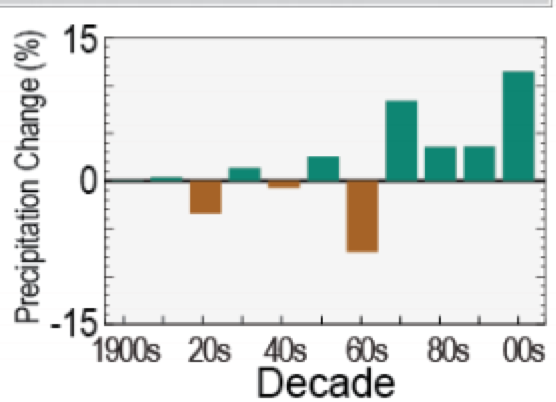


Figure 1.6. *Observed trends in heavy precipitation in the northeastern U.S. since 1900* (Melillo et al. *2014).*

2. Vermont's rising temperatures

Vermont average temperatures have increased 2.7° F since 1941. Since 1960, average temperature has increased 1.6° F, and since 1990, average temperatures increased 0.9° F. The last decade was the warmest on *record, with average temperatures increasing by* 0.4° F. [1]

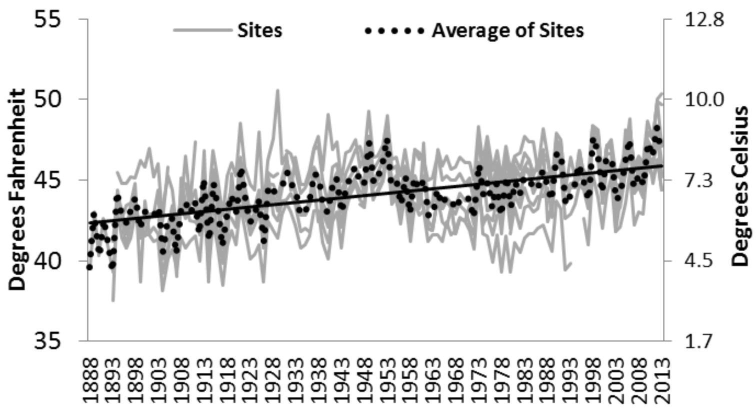


Figure 1.7. *Temperature change from 1888-2013 for 8 lowland (<1000 ft) climate sites in Vermont. Data source: (NWS 2014).*

Across Vermont, temperatures are warming, with increases occurring twice as fast in winter than in summer. Summer temperatures have increased by 0.4° F per decade over the last 100 years. Winter temperatures are increasing faster, at the rate of 0.9° F per decade with increasing variability, but a strong overall trend. In lowland regions, represented by 8 of the 12 Vermont climate sites, annual average temperatures have increased by 0.4° F per decade since 1960 (Figure 1.7). In the mountainous regions, represented by 4 of the 12 Vermont climate sites, annual average temperatures have increased by 0.8°F per decade since 1960 (Figure 1.8) (NWS 2014).

Average temperatures have been rising more rapidly in recent years. Averaging over lowland regions, annual average temperature increased by 1.5° F (0.8° C) degrees between 1990 and 2012, with an average increase of 0.7° F (0.4° C) degrees per decade. For highland regions between 1990 and 2012, annual average temperature increased 1.8° F (1° C), or 0.8° F (0.45° C)

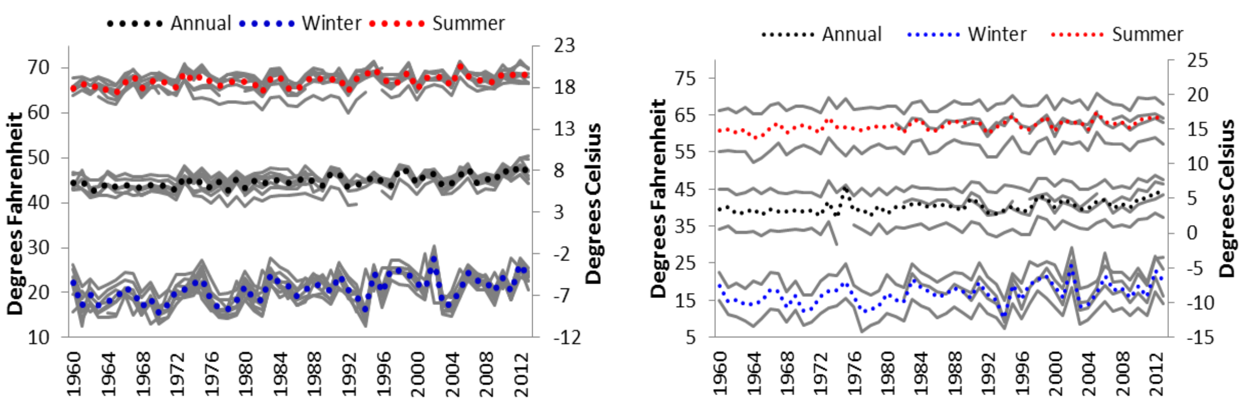
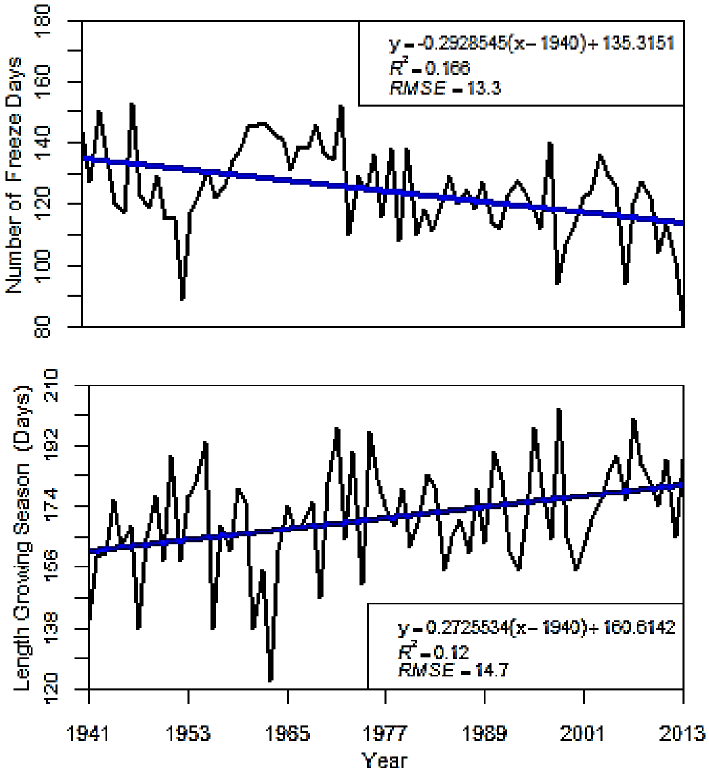


Figure 1.8. *Annual, winter, and summer average temperature change from 1960-2013 for lowland (left) and highland (> 1000 ft; right) climate sites in Vermont. Note the high amount of variability in average winter temperatures.*

[1] All climate data for Vermont were analyzed for this report and were provided curtsey of NOAA/National Weather Service and the Burlington regional office. NWS (2014). Observed Weather Reports. Burlington, NOAA/National Weather Service. Please see Appendix A for a complete list of weather stations used and www.VTclimate.org for temperature and precipitation trends by station annually and by season.

per decade. In the last decade alone (2000-2010), average temperatures in lowland areas increased 3° F (1.6° C); in highland regions, temperatures increased 2.5° F (1.4° C). Changes in annual average temperature have been affected by increasing winter average temperatures in recent years.

Figure 1.9. *Change in the length of the growing season (bottom) and number of days below 28° F (freeze days) recorded at the Burlington Airport.*



3. Winter severity

Winter severity in Vermont has and will continue to decrease as overnight low temperatures steadily climb.

As a result of warmer winters, rivers and lakes in Vermont have been frozen by 7 less days per decade. Spring has started 2-3 days earlier per decade, such that the growing season has increased by 3.7 days per decade. Vermont has already transitioned from hardiness zone 3-5 to 4 and 5 only, as a result of warmer winter minimum temperatures.

The winter severity in Vermont is decreasing even faster than warming is occurring. Local and regional temperatures are strongly regulated by snowfall. The winter warming trend is partially explained by lower snow cover that allows the land to absorb solar radiation and warm. A snow-covered surface reflects sunlight, helping maintain cooler temperatures. Evaporation from unfrozen snow-free land increases atmospheric water vapor, a strong greenhouse gas which traps heat and further warms the surface – a second positive feedback. A study in Saskatchewan demonstrated that the first snowfall causes temperatures to decrease by 18° F (10° C), with the reverse pattern happening with snowmelt (Betts et al. 2014).

One measure of winter severity is the number of "freeze" days (Figure 1.9, top). Freeze days occur when the minimum recorded temperature is at or below 28° F (-2.2° C). In Vermont, we see a 20% decrease

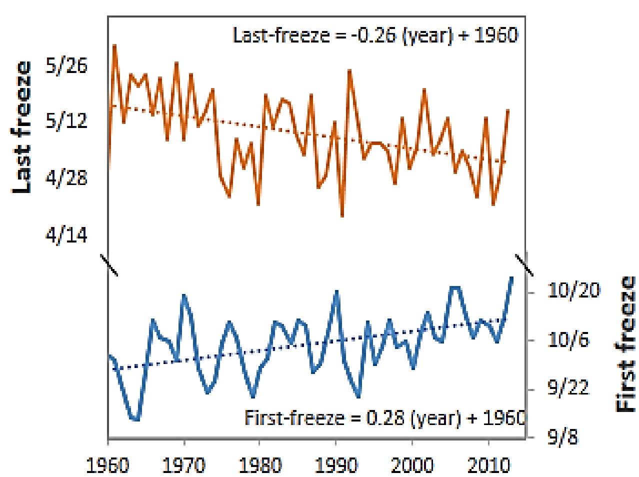
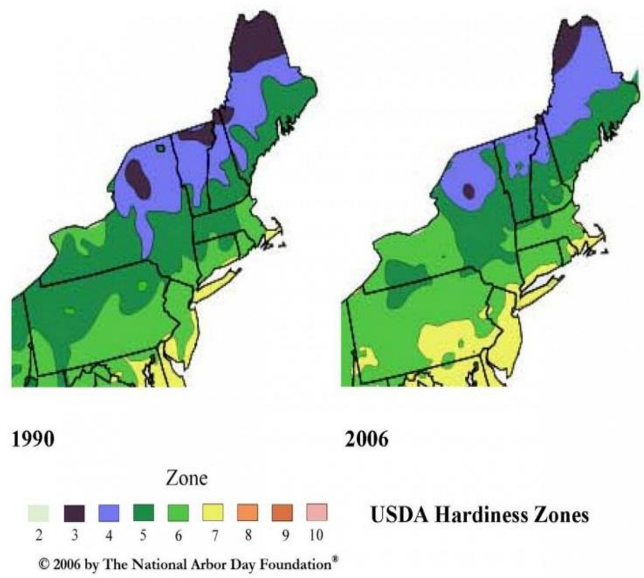


Figure 1.10. *Changes in the date of the first and last freeze since 1960.*

in the number of freeze days since the 1940s. During the 1940s-1960s, Vermont averaged 131 days below freezing each year. In the last decade, Vermont has averaged just 120 days below freezing each year.

Like the number of freeze days, the dates of first and last freeze are also changing (Figure 1.10). The date of the first freeze has been moving later in the fall by 2.8 days per decade since the 1960s. The date of the last freeze has progressed from mid- to late-May to as early as late-May, at a rate of 2.6 days earlier per decade.

Figure 1.11. *Change in USDA Hardiness Zones for the Northeast from 1990 to 2006.*



The decreasing winter severity means a lengthening of the growing season (Figure 1.9, bottom). The length of the growing season is defined as the number of days that are not freeze days. The growing season has steadily lengthened over the period of record from an average of 160 days in the 1940s to 176 days in the last decade (Figure 1.9, bottom). On average, growing season length has increased by 0.66 days per year since 1941. Since 1960, growing season has lengthened at a rate of 0.24 days per year.

Throughout Vermont, average winter temperatures have warmed 0.1° F (0.05° C) per year since 1940. For lowland areas only, winter average temperatures have increased 0.3° F (0.17° C) per decade since 1960; in mountainous regions, winter temperatures have increased by 0.2° F (0.1° C) per decade since 1960. Winter average nighttime minimum temperatures have increased from -20° F (-28.9° C) in 1940 to -12° F (-24.4° C) in recent years, a change of 1° F (-17.2° C) per decade. Warmer nighttime temperatures decrease snow cover, leading to warmer ground and air temperatures.

Farmers and gardeners measure winter severity in terms of plant hardiness zones as determined by the U.S. Department of Agriculture (USDA). These zones serve as a guide to which plants will thrive in their region. The zones are defined by the average annual winter minimum temperatures in bands of 10° F (-5.6° C). With lengthening growing seasons and warmer nighttime temperatures, Vermont is experiencing a change in its hardiness zones. In 1990, regions in Vermont were in the USDA's Hardiness Zone classes 3, 4, and 5. In the last decade, the zones have changed to predominantly classes 4 and 5 (Figure 1.11). This change in plant suitability may allow new, economically-important crops to be grown in Vermont. However, it may have negative impacts on native species adapted to this region. (See Chapter 6: Forests for more information on climate impacts on native forests.)

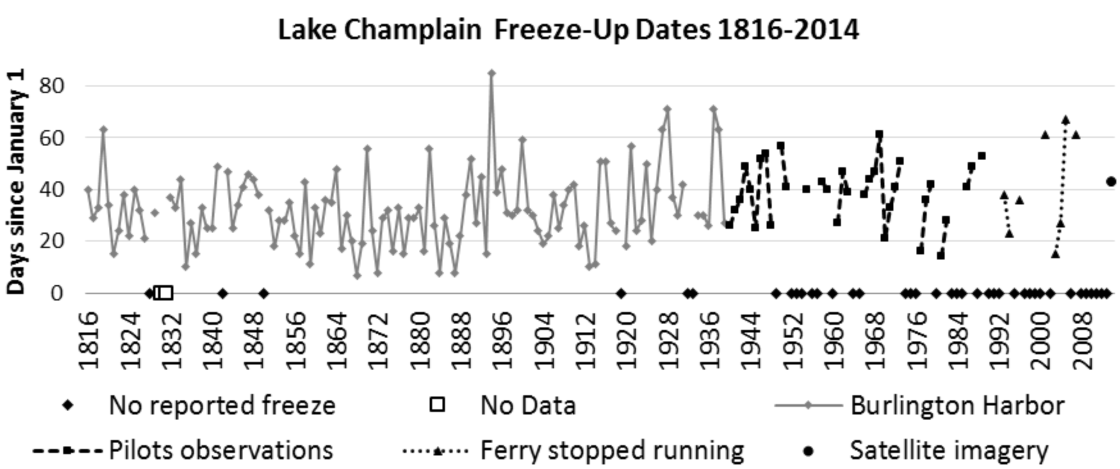
4. Frozen water bodies

One effect of rising temperatures is that Vermont's lakes are frozen 7 fewer days per decade. Because the natural climate of Vermont varies across the state, the impacts of human-induced climate change will not be smooth across the state or over time.

Ponds and lakes in Vermont will be frozen for shorter periods of time as winter temperatures warm. There is evidence that the warming trends discussed above have already decreased the length of the ice-covered season for many of Vermont's most famous water bodies (Figure 1.12). On average, Vermont's lakes are frozen for 7 fewer days per decade. This trend will likely continue into the future. Earlier trends in "ice out" correlate to temperature observations of warmer springs and shorter winter seasons.

The record of ice cover on Lake Champlain indicates less frozen periods over time, but the record should be eyed with some scrutiny (Figure 1.13). The methods, purpose and quality of observations for ice in Lake Champlain have varied greatly over time. In the 1880s, the "closing" of the ice on Lake Champlain was pertinent to commercial shipping that was more prevalent at that time than it is today. If Burlington Harbor were "closed" due to ice, the record may show the Lake was closed with no indication of the true extent of ice. Did this mean the whole lake was iced over? We may never know for sure. During the 19th C, records were sporadic. Circa 1910, The U.S. Weather Bureau Climatological Record Book for Burlington, VT reports the annual closing data for Lake Champlain from 1816-1871, with some citations from the Burlington Free Press. From 1872-1886, closings of the Harbor were recorded by Charles Allen dockside. From 1886-1906, records were kept by NWS cooperative weather observer Mr. W.B. Gates from the same dockside location. From 1906 onward, records have been kept by the U.S. Weather Bureau or National Weather Service, although the methods for determining the closing of Lake Champlain continued to vary throughout the 20th C. From the 1940s-1970s and perhaps 1980s,

Figure 1.13. *Timing of freeze-up on Lake Champlain shown by measurement type. From 1816-1940, freeze was defined as ice cover on Burlington Harbor. From 1940-mid 1980s, freeze up was noted as the time when the ferry stopped running due to ice. Since 2008, freeze-up has been measured by complete ice coverage on the lake, as measured by high-resolution satellite imagery (NWS 2014).*



many of the “closed” observations came from pilots flying over the lake and reporting they saw it iced over. From the 1980s-mid 2000s, the definition of “closed” was used only when the Ferry had to stop running due to ice—representing a much larger extent of ice cover than the 1800s definition. Since 2008, the National Weather Service has been using high-resolution satellite imagery to determine the date of complete ice coverage on the lake.

When the Lake does close with ice, it is now happening later in the winter. Given the amount of potential error due to different types of measurements, this is difficult to assess. Examining just the aerial and satellite observations (1940-present) shows an average delay in freeze-up of 0.4 days per decade, although this estimate has a high degree of error due to high-frequency noise inherent to the data set (RMSE 9.7).

Box 1.1. Joe’s Pond Ice-Out Contest

The Joe's Pond Ice-Out Contest benefits the Joe’s Pond Association Annual Fireworks fund and pays out roughly $5,000 to each year’s winner. Evolving from a topic of conversations around town, "When do you think the ice is going out?," friendly wagers were made until 1987 when the president of the Association turned the game into an official contest. The challenge came in determining a fair way to judge the exact date and time of ice-out, which occurred a little differently each year. Since 1988, a simple, low-tech control system has been in use. An electric clock was placed on H. Fitts’ deck with a tether to a cinder block wired to a wooden pallet placed 100 feet from the shore on top of the ice. When the block sinks, the clock is disconnected and records the “official” ice-out time. The winner is the contestant closest to the date and time of official ice-out. The contest has grown from a recorded 1,500 tickets in 1990 to over 12,000 in the last few years. In 2013, a few changes came to Joe’s Pond Ice-out Contest. The pallet and flag were moved to a new location and the old electric alarm clock was replaced with a weather-proof clock. Both the clock and pallet can now be monitored by webcam on the Joe’s Pond Association Ice-Out website (The Joe's Pond Association 2014).

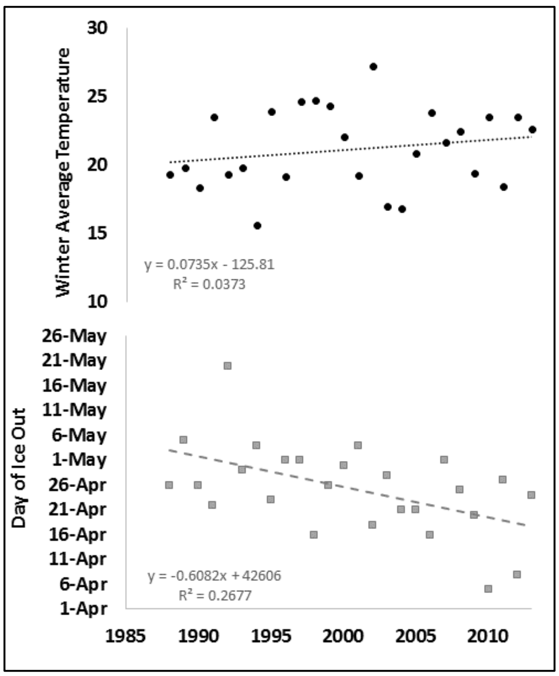


Figure 1.12. *A popular Vermont tradition is guessing the date of ice melt at Joe’s Pond in West Danville. Since its inception in 1988, the date of ice-out has come 7 days earlier. The day of Ice Out is significantly correlated to winter temperatures. During warmer winters, Ice Out happens earlier. Data provided by Joe’s Pond Associate and the National Weather Service for St. Johnsbury, VT as West Danville does not have a complete record (NWS 2014, The Joe's Pond Association 2014).*

5. Increasing precipitation

Vermont's annual precipitation is increasing by 1.0" per decade since 1941. Some parts of the state have experienced even greater increases, particularly mountainous regions. More winter and spring precipitation is projected for Vermont over this century, initially increasing snowfall but, as temperatures rise, later increasing winter rainfall.

Weather stations across Vermont show increasing precipitation, averaging an increase of 1.0" per decade since 1941 (Figure 1.14). Averaging over lowland areas in Vermont, annual precipitation has increased by 0.9" per decade since 1960. Annual precipitation in mountainous regions has increased 2.3" per decade since 1960. The amount of rain events with high intensity rainfall is increasing dramatically (Figure 15). From 1960-1980, Vermont averaged 4 days with precipitation greater than 1". For the last two decades, these intense precipitation events occur on average 7 days a year, with many observations over 10 days per year.

Figure 1.15. *Number of days per year with greater than 1" of precipitation (BTV station).*

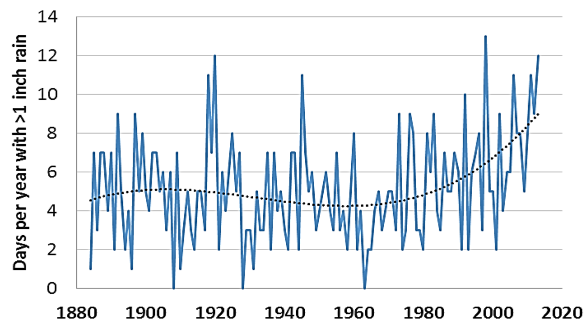
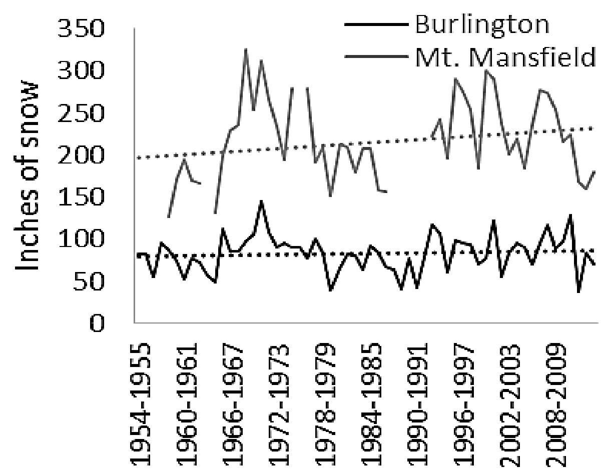


Figure 1.16. *Snowfall in Burlington and Mt. Mansfield 1954-2013.*



Snowfall increases so far have been more extreme in the mountainous areas than in the valleys due to cooler temperatures at elevation. For example, Burlington snowfall has increased 10% since 1954 while Mt. Mansfield snowfall has increased 22% (Figure 1.16). We expect annual snowfall to increase over the next 20-25 years and then decrease as temperatures warm to cause more rain than snow (Christensen et al. 2013, NWS 2014).

Snowfall is showing increasing variability, with record snowfall and much lower than average snowfalls coming year to year. Figure 1.16 highlights the variability in snowfall that may come from year-to-year. On average for the last 30 years, Vermont has had a cumulative snow depth of 573 inches. In the last three years, we

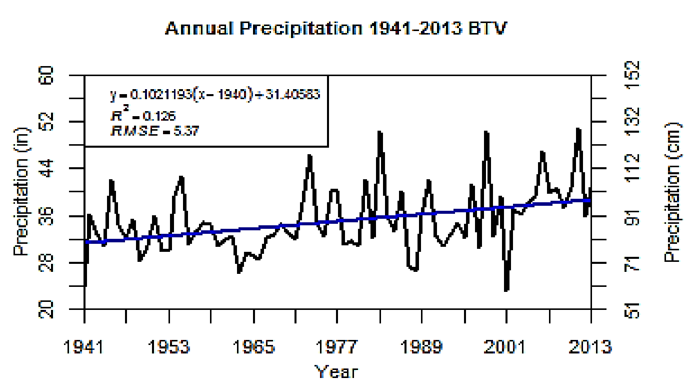


Figure 1.14. *Change in annual precipitation from 1941-2013 (BTV station).*

have seen a wide range of cumulative snow depths, from 80, 86 and 292 inches in 2011-2012, 2013-2014 and 2012-2013 to 1073 inches in 2010-2011 (Burlington Airport Station) (NWS 2014). Since 1960, low lying areas in Vermont have experienced a 1.1” decrease per decade in cumulative snow depth; in mountainous regions over the same time period, snow depth has decreased by 0.7” per decade. However, even average values across all climate sites have fluctuated widely since 1960, and this may not continue in the future.

6. Extreme Weather Events

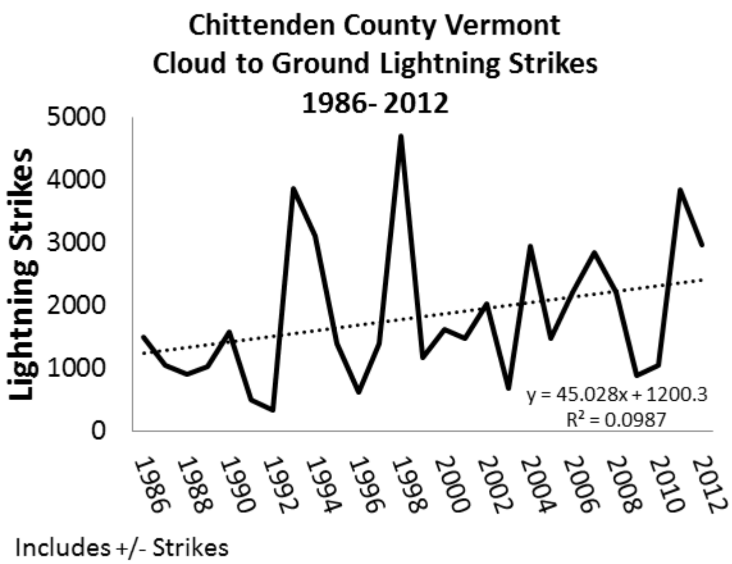
Certain types of extreme weather events have become more intense and frequent in Vermont, including floods, and high-energy storms.

Anecdotally, the impacts of extreme weather events are having an increasing impact on Vermonters. As precipitation becomes more flashy, that is, occurring in larger bursts over shorter periods, flood risk increases. Flooding in 2011 was devastating in some localities as Tropical Storm Irene swept through the region and delivered large volumes of water in just a few days. Further analysis of the state’s response to flood resiliency can be found in the chapters on community development, agriculture, and water resources.

In the winter of 2013-2014, the “polar vortex” engulfed much of the U.S. east of the Rockies, bringing ice and snow to 49 of the 50 states. In this weather pattern, the jet stream moves far south of its normal range and gets “stuck.” This “quasi-stationary blocking pattern” allows storm after storm to hit a region for weeks at a time. In 2013-2014, Vermont experienced this phenomena and had a number of colder than average periods for longer than average. During a similar quasi-stationary blocking pattern in May 2013, Vermont experienced multiple days of record rainfall, often over 4” per day. It is difficult, nay impossible currently, to predict how quasi-stationary blocking patterns will develop and affect Vermont’s climate in the future. This is because these patterns are new, having seldom been observed in the historical climate record so computer models of weather and climate lack sufficient data to predict and project these systems into the future. It is believed that the quasi-stationary blocking patterns are a result of melting sea ice. The loss of ice and resultant heating of the Arctic Sea decreases the surface pressure gradient from the equator to the North Pole. Under normal conditions, this pressure gradient guides the jet stream. Under a weakened gradient, the jet stream has the ability to move further south and end up in a short-term (1-3 weeks) blocking pattern. For more detail on this phenomenon, see recent articles by Francis 2013, Tang et al. 2013 and Francis and Vavrus 2012.

Globally, we expect climate change to increase the intensity of storms as heating of the atmosphere allows it to carry more water. Locally, we can use measured lightning strikes as a proxy for the energy carried in storms. Looking back to 1986, we see a generally increasing trend in lightning strikes (Figure 1.17).

Figure 17. *Chittenden County, Vermont: Cloud to ground lightning strikes.*



7. Changes in Lake Champlain

Changes in the water level and temperature in Lake Champlain show no evidence of significant changes due to climate.

Lake Champlain's water level is sometimes reported to be increasing. This is an artifact due to the damming of Lake's outlet in the late 1960s, which caused water levels to rise (Figure 1.18). Adjusted for the height changes due to the dam, there is no significant change in Lake Champlain's water level despite increased precipitation to the region.

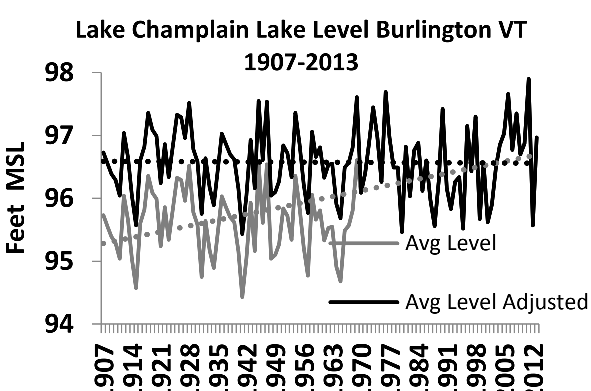


Figure 18. *Lake Champlain's annual average water level recorded at Burlington Harbor, VT. The adjusted lake level reflects the effects of damming the lake outlet and shows no significant change over time. (NWS 2014)*

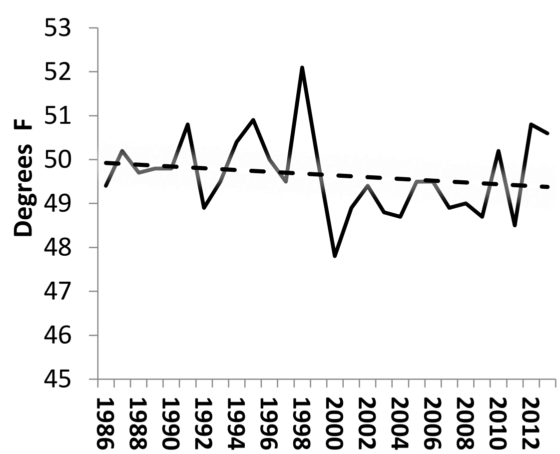


Figure 19. *Temperatures in Lake Champlain are slowly dropping due to increased water volume (NWS 2014).*

Another misconception is that water temperatures in Lake Champlain could rise due to warming atmospheric temperatures. In fact, water temperatures in the lake have been slowly dropping as the water volume in the lake has increased (Figure 1.19) (NWS 2014).

8. Summary Table Rating Quality of Information

<table>
<tr><td>Key Message 1</td><td colspan="4">Global climate is changing now, driven by human activities and amplified by water cycle processes, and this change is apparent across a wide range of observations. Global climate is projected to change over the next century, although the exact magnitude of climate change will depend primarily on the amount of global greenhouse gas emissions and the response of the climate to these emissions.</td></tr>
<tr><td>Description of evidence base</td><td colspan="4">Ninety-nine percent of scientists agree that climate change is happening now. This is documented globally (Christensen et al. 2013) and within the United States (Melillo et al. 2014).</td></tr>
<tr><td>New information and remaining uncertainties</td><td colspan="4">The Vermont Climate Assessment provides local analysis of changing climate that provides more detail for the state than national and international reports.</td></tr>
<tr><td>Assessment of confidence based on evidence</td><td colspan="4">Given the evidence base and remaining uncertainties, confidence is very high that climate change is happening globally and in Vermont.</td></tr>
<tr><td colspan="5">CONFIDENCE LEVEL</td></tr>
<tr><td colspan="2">Very High</td><td>High</td><td>Medium</td><td>Low</td></tr>
<tr><td colspan="2">Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus</td><td>Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus</td><td>Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought</td><td>Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts</td></tr>
<tr><td>Key Message 2</td><td colspan="4">Vermont average temperatures have increased 2.7° F since 1941. Since 1960, average temperature has increased 1.6° F, and since 1990, average</td></tr>
</table>

	temperatures increased 0.9° F. The last decade was the warmest on record, with average temperatures increasing by 0.4° F.
Description of evidence base	Evidence for the long-term increase in temperature is based on analysis of daily average, maximum and minimum temperature observations from the U.S. Cooperative Observer Network and the National Weather service (NWS 2014). A temperature increase is projected to continue rising (Christensen et al. 2013, Melillo et al. 2014).
New information and remaining uncertainties	A potential uncertainty is the sensitivity of temperature trends to bias adjustments that account for historical changes in station location, temperature instrumentation, observing practice, and siting conditions. For quality purposes in this study, we focused on stations that had not moved over time or had instrumentation problems.
Assessment of confidence based on evidence	Given the evidence base and remaining uncertainties, confidence is **very high** that temperatures in Vermont are increasing, with the greatest increases in winter temperatures.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Key Message 3	**Winter severity in Vermont has and will continue to decrease as overnight low temperatures steadily climb. Spring has started 2-3 days earlier per decade, and the growing season has increased by 3.7 days per decade. Vermont has already transitioned from hardiness zone 3-5 to 4 and 5, as a result of warmer winter minimum temperatures.**
Description of evidence base	Evidence for the changes in seasonality are documented in weather measurements across Vermont back to at least the 1960s (NWS 2014) and is expected to continue to change (Christensen et al. 2013, Melillo et al. 2014).
New information	More work should be done to understand how seasons will change across latitudes and elevations of Vermont.

and remaining uncertainties				
Assessment of confidence based on evidence	Given the evidence base and remaining uncertainties, confidence is **very high** that seasons in Vermont are changing.			
CONFIDENCE LEVEL				
Very High		**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus		Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts
Key Message 4	**One effect rising of temperatures is that Vermont's lakes are frozen 7 fewer days per decade. Because the natural climate of Vermont varies across the state, the impacts of human-induced climate change will not be smooth across the state or over time.**			
Description of evidence base	Evidence for changes in the freezing period for lakes and rivers comes from observational (NWS 2014) and empirical data (The Joe's Pond Association 2014). Precipitation is expected to continue increasing, following more as rain than snow by 2050 (Melillo et al. 2014).			
New information and remaining uncertainties	Using citizen observations, such as ice-out on Joe's Pond, is a new way to document local climate change. Collection of similar data sets from around the state would improve our understanding of Vermont's changing climate.			
Assessment of confidence based on evidence	Given the evidence base and remaining uncertainties, confidence is **very high** that water bodies are frozen for fewer days than in the past.			
CONFIDENCE LEVEL				
Very High		**High**	**Medium**	**Low**

Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Key Message 5	**Vermont's annual precipitation is increasing by 1.0" per decade since 1941. Some parts of the state have experienced even greater increases, particularly mountainous regions. More winter and spring precipitation is projected for Vermont over this century, initially increasing snowfall but, as temperatures rise, later increasing winter rainfall.**
Description of evidence base	Evidence for the long-term increase in precipitation is based on analysis of daily precipitation observations around Vermont (NWS 2014).
New information and remaining uncertainties	A potential uncertainty is the sensitivity of precipitation trends to bias adjustments that account for historical changes in station location, temperature instrumentation, observing practice, and siting conditions. For quality purposes in this study, we focused on stations that had not moved over time or had instrumentation problems.
Assessment of confidence based on evidence	Given the evidence base and remaining uncertainties, confidence is **very high** that precipitation in Vermont is increasing.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack

			of opinions among experts
Key Message 6	**Certain types of extreme weather events have become more intense and frequent in Vermont, including floods, and high-energy storms.**		
Description of evidence base	Evidence for the increase in high-energy storms has been directly observed with an increase in lightning strikes. Regional and national reports indicate an increase in high levels of precipitation in single rain events. These trends are expected to continue (Christensen et al. 2013, Melillo et al. 2014, NWS 2014).		
New information and remaining uncertainties	Quasi-stationary blocking patterns are expected to bring longer duration rains and storms in addition to the other causes of increase extreme weather events. Because these patterns were seldom historically observed, NOAA/National Weather Service has little information to inform their models to project when these blocking patterns might occur.		
Assessment of confidence based on evidence	Given the evidence base and remaining uncertainties, confidence is **very high** that extreme weather events in **Vermont** are increasing.		
CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Chapter 2: Climate Change Policy in the state of Vermont

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Key Messages

- **Vermont's ability to respond to a changing climate, maintain economic well-being and support its natural environment relies heavily on strategic policy planning and implementation. Local, regional and state policies and initiatives are imperative to adapting to climate change and reducing the impacts already underway.**
- **Current action at the state level centers around: 1) adaptation (e.g., infrastructure and land use planning), 2) mitigation (e.g., greenhouse gas emissions reduction programs) and 3) resilience through education and planning at the community and regional levels. Policy action is already well-underway, including the establishment of the Governor's Climate Cabinet in 2011; development of additional river corridor protection programs and authority in response to Tropical Storm (TS) Irene; and legislation to advance the state goals of a 50% reduction in greenhouse gas emissions by 2028 and 90% of energy from renewable sources by 2050. This is supported by a constituent base that values climate change action across the state.**
- **Proposed policy and management alternatives are being analyzed by Vermont's nonprofit and higher education organizations with input from stakeholders. Current programs in Vermont are focused on building local-level capacity, working to understand the critical social networks for climate change education and adaptation, and planning for future sustainability.**
- **State policies are designed as collaborative efforts across various sectors involving a variety of perspectives through levels of government and volunteer networks. Such collective action is necessary to effectively address the threats of climate change to our social, economic and environmental well-being in Vermont.**

DEFINITIONS

Resiliency: is the capability of social and or natural systems to respond to and recover from climate change events.

Adaptation: is the process of adjustments that social ecological systems make in response to changing situations to reduce vulnerability from climate change impacts.

Mitigation: is a proactive process that moderates climate change disruption through reducing our overall contribution to emissions.

The ability to build resiliency depends on successful adaptation and mitigation strategies being implemented across social and natural systems. Climate change policy in the state of Vermont should aim to build resiliency through both adaptation and mitigation practices.

0. Introduction

This chapter serves to provide a background on the development of Vermont Climate Change Policy and an overview of current programs in place. It includes a brief but comprehensive overview of the programs and policies and how they were established. Additionally, this introductory chapter outlines some of the opportunities and challenges that have arisen throughout the process and prompts future critical thinking for planning in the short and long-term with regards to projected climate change impacts to the State of Vermont. Major climate change threats are addressed through state policies regarding: air pollution, flooding, energy, natural disasters, and emergency response.

Current priorities include: ***1) reducing greenhouse gas (GHG) emissions, 2) transitioning to more renewable energy sources, 3) undertaking state-level research on climate change, and 4) building statewide resilience to climate change.*** This chapter breaks these priorities into two categories, those that are primarily focused on mitigation and those that are primarily focused on adaptation (note the definitions of mitigation and adaptation at the beginning of this chapter). Policies aimed at adaptation have primarily focused on community flood resilience (response to TS Irene), but include other topics (economy, tourism, agriculture). Mitigation programs have focused on greenhouse gas emission reduction and efficiency and renewable energy solutions that contribute to emission reductions.

1. Adaptation Policies and Programs

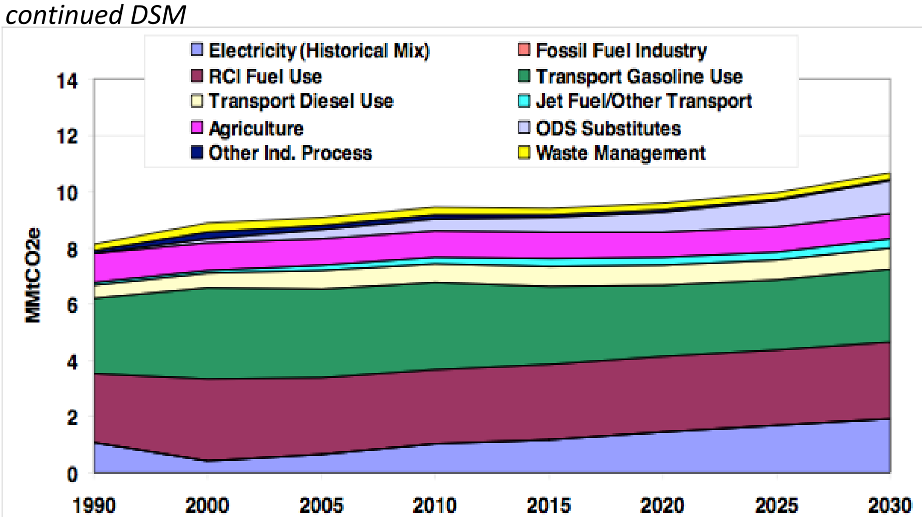
1.1 ***State Level Planning for Climate Change Research: 2005 – Governor's (Douglas) Commission on Climate Change[2]:*** The Commission on Climate Change was a two-year, multi-stakeholder effort. It included six commission members; thirty-one plenary group members; four sector-based technical working groups. In 2007 a major report was published as a comprehensive review of the state's emissions and potential reductions in four broad categories, 1.) Energy Supply and Demand, 2.) Transportation and Land Use, 3.) Agriculture, Forestry and Waste and 4.) Cross Cutting Issues (e.g. GHG emission inventory, Public Education and Outreach, Adaptation, State Operations Emissions). The culminating result was a presentation of 38 policy recommendations and over 200 proposed actions to identify the efficiency measures generally most cost-effective with the highest potential for success in Vermont. While the overarching goal is to reach attainment of all policy recommendations, the Commission acknowledges the need for further analysis of many of the options (ANR, 2007). In order to start this process the Commission identified six overarching recommendations for the Governor to prioritize:

1. Building on Vermont's Energy Efficiency Leadership and Renewable Energy Potential
2. Keeping Our Farms, Farms and Our Forests, Forests

3. Reducing Emissions in a Renewed Transportation System Within and Between Vibrant Town Centers
4. Educating and engaging Vermonters about Climate Change
5. Leading by Example
6. The Vermont Climate Collaborative: A Signature Partnership of Vermont's Government, Academic, and Private Sectors

These six primary categories are driving strategies to respond to GHG emission reductions across sectors. Figure 2.1 shows the gross GHG emissions, historically and projected, broken out by sectors that correlate with the six priority areas.

Figure 2.1 Vermont GHG emissions by sector, 1990 – 2030: assuming continued DSM



* Based on low-emission scenario for the electric utility sector (i.e., historic hydro and nuclear power supply levels)
DSM – Demand Side Management (utility and consumer efficiency actions to reduce power demand, and hence emissions)
RCI – Residential, Commercial and Industrial
ODS – Ozone Depleting Substances (which are also powerful greenhouse gases)

For a table list of the full 38 policy recommendations, please see page 9 of the Plenary Group Recommendations Appendices at ANR Climate Change team website.

As part of the continued policy focus on responding to impacts from climate change and working to achieve the Climate Change Commission goals, a cross-agency cabinet was formed in the spring of 2011. The Cabinet's work is guided by four priorities: (1) increasing the use of hybrid electric vehicles; (2) implementing the new energy plan; (3) reducing emissions from state buildings and operations; and (4) developing good metrics to track Vermont's progress. The Climate Change Cabinet brings together agency members and focuses on meeting the state's ambitious climate adaptation goals through the organization of five working groups. The working groups are assigned unique tasks to work on as they pertain to the policy recommendations from the climate change commission (Johnstone, et al., 2010).

Climate Change Team Working Groups

Electric Vehicles State Operations Data & Metrics Flood Resiliency Health

The work of these groups is accomplished by members of the Climate Change Team which is staffed through the Climate Cabinet with representation from 8 State Agencies. Each group has taken on the responsibility of working with different sets of priority recommendations from the

Commission on Climate Change. For example, the state operations working group leads projects such as evaluating and implementing state fleet efficiencies, carpooling/ride share, teleworking, web conferencing and so on.

The 2007 report from the Governor's Climate change Commission also recommended the state develop a comprehensive Climate Change Adaptation Plan (Tetra Tech and ANR, 2013). In result, there are a multitude of past and ongoing efforts focused on climate change at the state planning level. Below is an outline of some of these programs and initiatives. More information can be found on the state's websites as outlined in Table 2.1.

Table 2.1 *State-level planning efforts related to climate change*

Vermont Climate Collaborative http://www.uvm.edu/~vtcc/	Established October 2008, retired May 2011. Originally conceived by Governor Douglas / President Fogel as a research coordination body. Evolved into a stakeholder information exchange forum.
Vermont Climate Cabinet http://www.anr.state.vt.us/anr/climatechange/ClimateCabinet	The Vermont Climate Cabinet was established in May 2011. The cabinet includes members from the Agencies of Natural Resources (Chair), Agriculture Food and Markets, Commerce & Community Development, Economic Housing and Community Development, Administration, Building and General Services, Public Service Department, VTrans, and Department of Health.
Vermont Climate Change Team http://www.anr.state.vt.us/anr/climatechange	In order to help achieve the goals set forth by the governor and the State of Vermont, the Agency of Natural Resources has convened a Climate Change team to focus on identifying climate-related threats and recommending solutions to mitigate impacts. The team works to understand and implement adaptation strategies that will enable the state to be better posed to handle the impacts of climate change.

1.2 *Agency of Natural Resources Vulnerability Assessment: Adaption Framework for Natural Resource* Sectors

This year-long process included two stakeholder engagement opportunities – vulnerability assessment and adaptation. This project examined the effect of a changing Vermont climate on four important habitat/ecosystems: lakes and ponds; rivers and streams; upland forests; and wetlands. The primary structure included a review of current climate forecasts, incidence of exposures to climate change and measurement of vulnerability as expressed by (Exposure x Sensitivity) – Adaptive Capacity. The measurement assumes that climate change increases

Table 2.2 *Common climate change themes relevant to the four main habitats of Vermont* exposure to stress. Sensitivity is partially a function of other stressors (habitat loss, toxics). Adaptive capacity varies with species and the related stressors. The results found certain common themes across habitat groups (Table 2.2).

Common Themes	Potential Results
Compositional changes associated with changing climatic conditions (long-term, localized effects could occur on shorter timescale)	Loss of cold-adapted species; Increase in warm-adapted species
Increase in physiological stress (immediate)	Particularly concerned about summer heat and/or water limitation; Note: Champlain Valley is naturally hotter and drier than other parts of VT.
Increase in susceptibility to disease and pests (immediate)	Increased risk of threat to health of habitat groups
Increase in disturbance (i.e. from extreme storm events) (immediate)	Facilitates the spread of invasive plants and species

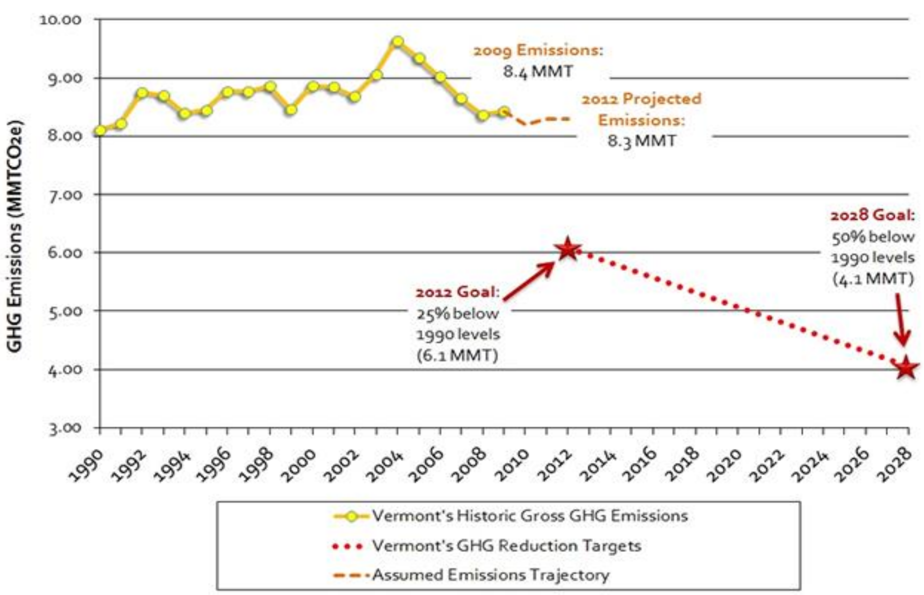


Figure 2.2 *GHG Measured emissions compared to 2012 – 2028 goals. Source: http://www.anr.state.vt.us/anr/climatechange/Vermont_Emissions.html*

2. Mitigating Policies and Programs

2.1 *Reducing Greenhouse Gas Emissions:*

In 2005, Vermont set a goal of reducing emissions 25% below 1990 levels by 2012. Figure 2.2 shows this goal was not met, even though there has been a decrease in Vermont's total emissions since 2004. The aggressive goals set forth by the Governor's (Shumlin) Comprehensive Energy Plan, passed by legislature in 2012, requires continued active effort and as the plan calls out in its executive summary, "will not wait for slow policy development or be cured by small progress (PSD, 2011)." The Vermont legislature established statewide GHG emission reduction goals (GHG Emissions Goals 10 VSA $578 (2005)) in 2005 based on the **New England Governors and Eastern Canadian Premiers (NEG-ECP) Climate Change Action Plan, 2001,** emissions "Lead by Example" goals for state Governments. The baseline year used is 1990, and the baseline emissions that the reductions are calculated on is 8.11 MMTCO_2e (this is the measurement unit that expresses million metric tons of carbon dioxide equivalent). Vermont's goals describe a fairly aggressive reduction trajectory (Table 2.3).

Table 2.3 *Vermont's greenhouse gas emission reduction goals*

Goal	Target Date
25% reduction from 1990 levels (6.1 MMT CO_2e). (Actual reduction from 1990 levels was not achieved by target date)	1/1/2012
50% reduction from 1990 levels (4.1 MMT CO_2e)	1/1/2028
75% reduction from 1990 levels (2.0 MMT CO_2e) if practicable using reasonable efforts,	1/1/2050

The Regional Greenhouse Gas Initiative helps to support Vermont's GHG reduction goals and helps to provide resources and funding for enhancement of energy efficiency programs across the state.

2.2 Regional Greenhouse Gas Initiative (RGGI):

The RGGI program established a regional partnership to reduce greenhouse gas emissions from electrical generation facilities across 10 states in the northeast from Maine to Maryland. This initiative was the first market-based regulatory program created in the United States to reduce greenhouse gas emissions. Originally proposed by NY Governor Pataki in 2003, the initiative was actually launched in 2009, and the 10 states involved have cooperatively achieved great successes. The only state no longer involved in the initiative is New Jersey which withdrew in 2012. Emission permit auctioning began in September 2008, and the first three-year compliance period began on January 1, 2009. Proceeds are used to promote energy conservation and renewable energy. Although, as of 2010, three states had used some of the money to balance the overall budget. The original number of GHG emission allowances allotted to Vermont and other states were so large that the program didn't result in a direct reduction of emissions. Rather the funds raised by the auctions were used to promote programs that are working to reduce emissions in Vermont (such as the Home Energy Challenge described below). Figure 2.2 outlines investments made by program type as of 2012 data.

The program uses a cap-and-trade market-based approach to reducing greenhouse gas emissions. Essentially, each state is given a share of allowances, each allowance equal to 1 metric ton of CO2 emissions. The states then sell these emission allowances through an auction process. States can then invest the proceeds in energy efficiency projects, like the Home Energy Challenge, a program for increasing energy efficiency projects by homeowners. Investments can also made in a multitude of renewable energy projects and other clean energy technologies. In Vermont, RGGI funds are used to support the state's energy efficiency utility Efficiency Vermont.

Figure 2.3 *RGGI Investments by Program Type (RGGI.org)*

As an indicator of success, after three years of running, the cap of allowed emissions from regulated power plants was 165 million tons in 2013, but the actual emissions measured in 2012 only totaled 91 million tons. Representative of the program's ambitious nature, a significant tightening in the cap was announced in 2013 for the second compliance period going through 2015 bringing the allowance of emissions down to 91 million tons (a 45% reduction) with a plan for a continued 2.5% annual decrease through 2020. While these figures point to the success of the overall initiative, the decrease in emissions below the cap is likely due to the increased use of natural gas and other economic variables. Nonetheless, there are various highlights to be mentioned pertaining to Vermont's success with the program. Funding from RGGI has helped the Vermont Community Energy Mobilization Project, a volunteer-based program that works with private homeowners (Efficiency Vermont, 2013b). This program has successfully installed home energy-saving measures estimated at 590,000 kilowatt-hours of electricity and 1,750 MMBTU of heating energy since 2010. Additional funding from RGGI has also allowed for the Efficiency Vermont Home Energy Challenge to provide incentives up to $2,500 for home energy retrofit projects. Total revenue to VT: $740,000 in 2012 to Vermont Energy Investment Corp through the Public Service Department (PSD). Participation in RGGI coupled with Efficiency Vermont's contributions to the regional grid, have also fund Vermont's thermal energy and process fuel efficiency programs that support the delivery of energy efficiency services to Vermont heating and process fuel consumers. The result includes cost-effective efficiency measures and reductions in greenhouse gas emissions from those sectors (RGGI, 2012a). Collectively, the RGGI programs contributing to heating and process fuel efficiency programs have served 2,400 households and 130 businesses. According to the American Council for an

Energy Efficient Economy, Vermont was the fifth in the nation in making energy efficient investments in 2012 (RGGI, 2012b).

***2.3 Renewable Energy Solutions, VT Legislature Energy Acts*:**

The Vermont legislature has addressed the state's future energy use many times over the past 25 years, with a focus on energy efficiency and more recently renewable energy development. Energy costs and reliability have been important criteria in new legislation. Programs of particular interest include:

- Efficiency VT, developed in 2000 to promote education and technical assistance to Vermonters in order to reduce energy costs, bolster local economy and mitigate negative environmental impacts by increasing energy efficiency across homes and businesses around the state, initially with a focus on reducing electrical energy consumption
- SPEED Program (Sustainably Priced Energy Enterprise Deployment) Enacted by the Vermont legislature in 2005 with a goal to increase the development of in-state renewable energy sources using renewable fuels. The program set a goal to reach 20% of total statewide electric retail sales to be SPEED resources comprised of new renewable energy during the year starting on January 1, 2017. One of the current criticisms with SPEED renewable projects is that they are allowed to sell their renewable energy credits into the regional market (since VT does not have a Renewable Portfolio Standard). Some consider this "double counting" of renewables, and believe that it doesn't result in any net increase in renewable generation in the region. Earlier this year, CT acted to make RECs purchased by regulated entities from VT renewable projects ineligible for credit toward their RPS.

Upcoming issues pertaining to Vermont's renewable energy transition goals revolve around improving a plan to implement a renewable portfolio standard for electricity, completing a total energy study and enhancing thermal efficiency infrastructure. In 2008, the State set a goal to building thermal efficiency to improve substantially the energy fitness of at least 20 percent of the state's housing stock by 2017 (more than 60,000 housing units), and 25 percent of the state's housing stock by 2020 (approximately 80,000 housing units). See *Chapter 4: Energy* for more information on energy and climate change in Vermont.

2.4 *Comprehensive Energy Plan 2011:* The Vermont Public Service Department (PSD) is required by Statute 30 VSA 202(b) dated 1981, to update state's Comprehensive Energy Plan (CEP) every 5 years. The last plan was completed in 1998. In 2011, Governor Shumlin reaffirmed this requirement and the PSD published a new Comprehensive Energy Plan in December 2011. In 2011, Governor Shumlin reaffirmed this requirement and the PSD-produced plan by the end-of-year deadline. The Statute requires that the plan's revision process include a statewide stakeholder process of public hearings. Vermont's 2011 CEP established the goal of 90 percent of the state's energy coming from renewable sources by the year 2050. The PSD is now in the stakeholder engagement planning process as part of the Total Energy Study to meet this new goal for the next report due out in 2016. After the release of the TES, there will be a second round of stakeholder meetings as part of the planning process for the CEP. For more information and the full report please see the Public Service Department's website.

2.5 *Total Energy Study - Public Service Department:* The total energy study was commissioned as a requirement by legislature in the Energy Act of 2012. The act reads reaffirms the 90% renewable goal by 2050 while meeting the following statutory goals:

Table 2.4 *Statutory goals for meeting greenhouse gas emission reduction goals in the Energy Act of 2012*

Goal	Target Date	VT Statute
127.5 MW of new in-state renewable electric generation contracts provided through the Standard Offer program of SPEED	2022	(30 V.S.A. § 8005a(c))
25% of all energy from in-state renewables	2025	(10 V.S.A. § 579(a))
50% reduction in greenhouse gas emissions; 75% by 2050	2028	(10 V.S.A. § 578(a))
75% renewables in electric sales	2032	(30 V.S.A. § 8005(d)(4)(A)

The Public Service Department has initiated a process to develop information in support of the next CEP. During the summer of 2013 the PSD organized and facilitated stakeholder focus groups on ten energy topics (e.g. electrification, solid biomass, liquid biomass, other renewables, residential energy, commercial building and industrial energy, transportation and land use, alternative fuel vehicles and infrastructure). The overarching goal of the focus groups was to gather information to provide to the state's contractor who is working to develop alternative technology and policy sets that can achieve the act's stated goals. Figure 2.4 illustrates the current mix of energy in Vermont, grouped by energy type and then summarized into three principal sectors, transportation, residential and commercial and industrial.

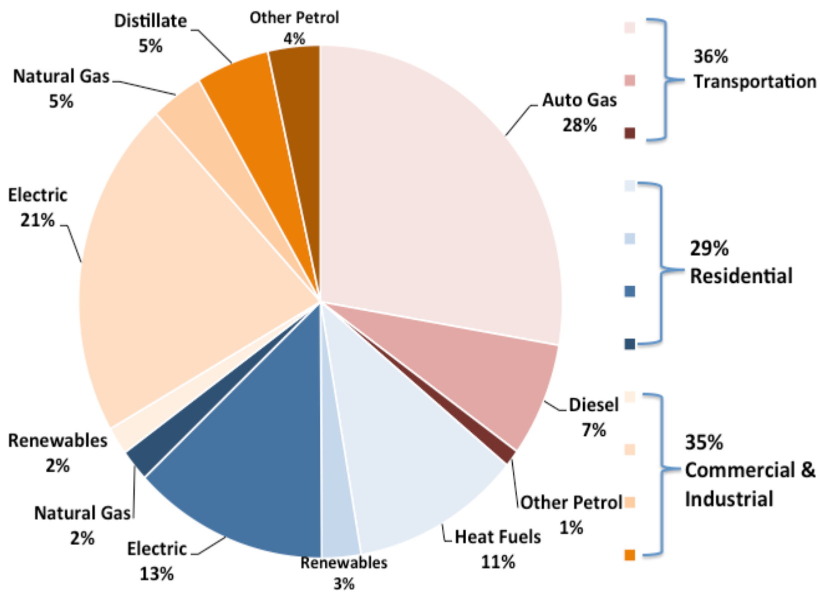


Figure 2.4 *Vermont's 2011 Energy Breakout by Sector and Energy Type*

2.6 *Energy Siting Commission 2012*: The energy siting commission was created by the Governor's Executive Order October 2012, in response to concerns regarding process for issuance of a Certificate of Public Good for Renewable Energy projects (particularly utility-scale wind). This commission was tasked with providing guidance and recommendations on best practices for the siting approval of electric generation projects larger than the net metering threshold. It also served to spur public participation and representation in the siting process (PSD, 2013a). The report, published in April of 2013, contains the following recommendations to be presented for consideration by legislature:

- Increased emphasis on planning at the state, regional and municipal levels, such that siting decisions will be consistent with RPC plans
- Adopted a simplified tiered approach to siting
- Increased opportunities for public participation, and increased transparency, efficiency and predictability of the process
- Updated environmental, health and other protection guidelines

The recommendations have helped to provide a strong foundation for both identifying valid issues and for future planning to move towards increasing levels of renewable energy consumption for the state. The key recommendations for siting present a plan that suggests the public service board interacts closely with regional plans for review and approval to be consistent with the state statutes. Additionally, municipal plans would be considered and reviewed carefully to be integrated into the regional and state goals. The end goal is that these recommendations will help to engage towns and regions more effectively in the state's energy planning and increase their roles in achieving Vermont's renewable energy goals.

2.7 ***Thermal Efficiency Task Force 2012***

Final Report January 2013: Recommends public investment of $27M in 2014 to $40M in 2020 to meet statutory weatherization goals. The status of these decisions will very likely be discussed in the upcoming legislative session. It is unclear if PSD will put forward a proposal or if key legislators will lead the discussion. Either way, the hope is that these funds would leverage approximately twice as much private investment. The idea is that public money will encourage financial institutions to lend for the balances, since loan amounts (and presumably risk) will be reduced (PSD, 2013b).

2.8 Vermont-Quebec Electric Vehicle Charging Corridor:

The State of Vermont has invested in a 138-mile corridor of Electric Vehicle (EV) charging stations. This project was conceived during the 2012 NEG-ECP. Developed by the Agency of Natural Resources and administered by the Agency of Commerce and Community Development, this initiative provides financial resources for electric vehicle charging stations in all of Vermont's designated downtowns. Acknowledging that the transportation sector is one of the biggest contributors of greenhouse gas emissions the State recognizes this investment as a priority in responding to strategies for transition to lower environmental impacts from vehicles. In part from support like this, the adoption of electric vehicles in Vermont has been following an upward trend, as of July 31st, 2012 nearly 300 electric vehicles were registered throughout 100 cities and towns in Vermont (EIC, 2012).

3. Building Statewide Resilience to Climate Change

3.1 *Act 16 of 2013 – Municipal and Regional Flood Planning and Flood Resilience*

In July 2013, the legislature passed a new ruling to encourage flood resilient communities in Vermont. The act requires:

(A) New development in identified flood hazard, fluvial erosion, and river corridor protection areas should be avoided. If new development is to be built in such areas, it should not exacerbate flooding and fluvial erosion.

(B) The protection and restoration of floodplains and upland forested areas that attenuate and moderate flooding and fluvial erosion should be encouraged.

(C) Flood emergency preparedness and response planning should be encouraged.

Municipalities must work to update their town plans to include the flood resilient element either as a part of their land use section or in an existing flood section of their hazard mitigation plan if they have an adopted plan in place. The state is providing support through the Agency of Natural Resources and regional planning commissions around the state are also helping to guide towns in the process. The act goes into effect July 1, 2014 and will hopefully be influential in shaping a new perspective of land use planning that better mitigates and plans for risk of flooding events across the state. To provide support, ANR works with municipalities and regional planning commissions directly and has also published a website to help guide planners through the necessary steps for updating a town or regional plan (ANR, 2013).

Figure 2.6 *Resilient Vermont wordcloud from Institute for Sustainable Communities*

3.2 *Resilient Vermont Project – Institute for Sustainable Communities*

The Institute for Sustainable Communities, a nonprofit organization located in Montpelier and focused on helping communities around the world address environmental, economic and social challenges, has been engaged in an 18 - month stakeholder engagement process to evaluate policies and programs for 'Preparing for Natural Disasters and the Effects of Climate Change in the Green Mountain State'. The Resilient Vermont project, organized by ISC and supported by the High Meadows Fund, the Waterwheel Foundation, Jane's Trust, Lintilhac Foundation, and generous donors to ISC's Climate Fund, has partnered with the State of Vermont, the Vermont Natural Resources Council and the Vermont League of Cities and Towns to work towards making Vermont a model of community, economic and environmental resilience. The idea of this project is to provide decision makers and stakeholders from across state and local governments, businesses and non-profits with information on strategies to mitigate risks of climate change and future hazards to our environment and economy. The project has relied on and continues to engage citizens and communities concerned with the growing challenges of extreme weather events and the vulnerabilities we currently experience in the face of damaging natural disasters. Strategies and priorities for actions towards creating a more resilient landscape focus on strengthening Vermont's ability to adapt to changes and to reduce negative impacts on the environment, economy and communities.

The process has included a variety of stakeholder events through which ISC has collected information on work going on around the state relating to preparedness for changes in weather events, like Tropical Storm Irene of August 2011. The final output of the program is to provide information on specific vulnerabilities and direct attention through policy and program recommendations to priority areas for building resilience. The culminating report from the project includes recommendations that present solutions and strategies for building capacity of Vermont organizations and state agencies to engage in a long-term sustainable plan for a stronger more resilient Vermont. ISC has fervently worked to put together the most complete compilation of work going on around the state and glean from this body of knowledge both a current assessment of vulnerabilities facing Vermont by sector and an outline of opportunities for action moving forward (ISC, 2013).

3.3 *Recommendation for Vermont Climate Action Plan*

A strong policy recommendation for Vermont could be a formalized Climate Action Plan. Vermont already has a multitude of programs, policies and projects completed or underway that would serve as the components of a climate action plan. Specifically, the policy recommendations from the Commission on Climate Change cover many topics and strategies that climate action plans hold in other locations across the country. Commonly seen through city planning processes, climate action plans lay out strategy and goals that combine work across sectors and across government levels for a stronger unified force in responding to climate change. Plans encourage broad participation for creation and demand continuous progress evaluation towards meeting goals. With examples of innovative strategies for responding to climate change, the climate action plans adopted in cities like Chicago, New York, Seattle and Portland could inspire Vermont to take the necessary steps to formalize many of the great efforts thus far. A Vermont climate action plan would assure continued action and support into the future for both near term and long term adaptation and mitigation strategies to become increasingly resilient to climate change impacts.

Box 2.1 *Portland, OR—first local government in the U.S. to adopt a strategy to reduce carbon emissions*

In 2009, the City Council of Portland, OR passed, at the time, one of the most aggressive climate change policy programs to reduce greenhouse gas emissions. The vote was passed unanimously, 4-0 and outlined a 40 year plan to reduce GHG emissions 80% below 1990 levels by 2050. The goals are outlined in a Climate Action Plan that incorporates the surrounding Multnomah County, addresses energy use in buildings, transportation, urban planning and agriculture. There is a strong focus regarding building a local green economy that aims to contribute to deepening the foundation for success in achieving the plan's goals. The plan is comprised of 93 actions that are to be reviewed every three years to monitor progress. Some specific targets include: Net zero GHG emissions in new homes and buildings; Energy use in current buildings reduced 25%; and Neighborhoods designed so 80% of county residents (90% of city residents) can walk or bicycle to meet daily needs. Miles driven per day reduced 30% per person. Solid waste reduced 25%. 90% of waste reused or recycled. Locally grown food increased significantly Urban forest expanded to cover a third of Portland (Daily Sustainable Business News, 2009).

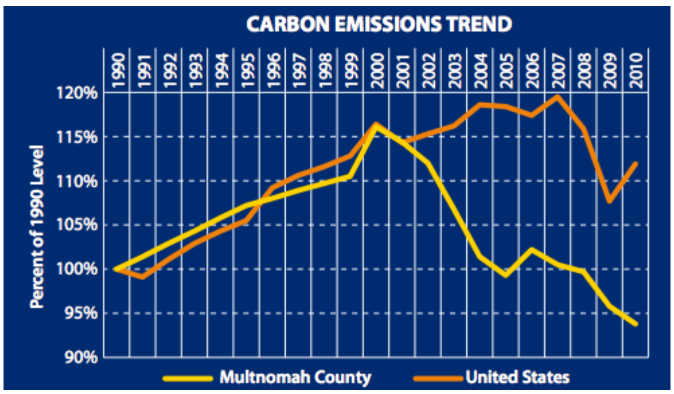


Figure 2.7 *Carbon emissions trends from 1990-2010 in Multnomah County and the U. S.*

The 2012 review reported a success story as carbon emissions landed on a downward trend. Additionally, the report cited that emissions from home energy use had declined 7% from 1990 levels with over 1,000 homes going through weatherization process through Clean Energy Works Oregon, solar panel installations on over 1,400 homes and businesses and nearly 150,000 households compost food scraps at the convenience of curbside pickup by the city (BPS and OS, 2012).

The two year progress report also shows that of all actions outlined in the 2009 Climate Action Plan, 58% are on track and 12% have been completed. Of particular importance to achieving these actions has been the coordination across numerous bureaus and departments within two different agencies and the host of community partners dedicated to the success of the City Council's mission in reducing carbon emissions and mitigating the pace of climate change.

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Supporting Work

Brian Woods, Climate Change Team, Agency of Natural Resources, Air Quality Division.

Linda McGinnis. 2013 Siting Commission Presentation: Siting Electric Generation in Vermont: Analysis and Recommendations. The Governor's 2013 Energy Generation Siting Policy Commission.

Chapter 3: Community Development

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Key Messages

- **Rural and urban communities around Vermont are at risk of climate change impacts, from both steady changes over time in temperature and precipitation as well as single occurrence extreme weather events. Impacts are forecasted to continually shape communities, as climate affects Vermont's primary economic sectors such as agriculture, recreation, tourism, and forest products. Many communities have already been highly impacted and are engaged in processes to respond to climate change related transitions through formal planning.**

- **Communities across the state are undergoing adaptation planning. Climate change impacts will continue to require adaptation planning on local, regional and state levels. Regional and watershed based planning perspectives will become more crucial as the State works to protect its important economies and communities. Land use planning must acknowledge climate change impacts via smart growth development strategies, improved stormwater management and flood resilient planning.**

- **The infrastructure systems of Vermont's communities are highly vulnerable to climate change. A mountainous, rural geography combined with small rural communities with limited transportation routes and communication systems elevate this vulnerability. Antiquated water infrastructure and aging built-infrastructure pose additional challenges, particularly given limited economic resources available for adaptation.**

- **Resilient communities will engage in hazard mitigation planning to respond to increased emergency response needs from vulnerable populations, rural communities and areas that have been exposed to extreme weather events, particularly flooding. The State will need to continue to lead in hazard mitigation planning and provision of guidance and support to local communities.**

This chapter underscores the importance of understanding community dynamics particular to the State of Vermont in building strategies to respond to the risks of climate change. Building resilience on a community level is typically connected to adapting land use practices and assessing infrastructure vulnerabilities to prioritize recommendations for adapting to weather related damages and mitigating future risks. The Vermont Climate Assessment Community

Development chapter aims to detail the current impacts of climate change on communities in Vermont and the current and potential strategies that can be applied in response.

1. Many communities have already been highly impacted by changes in weather and are engaged in processes to respond to climate change related transitions.

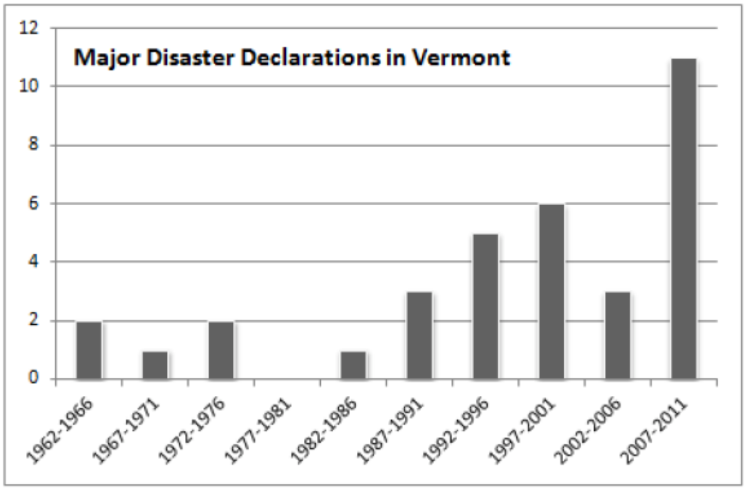


Figure 3.1: *FEMA major disaster declarations in Vermont in five year increments. Adapted from VTrans Climate Change Adaptation White Paper.*

1.1 Land Use: Land use planning is a principal component of community planning for climate change. Changes in climate are already forcing communities to reevaluate land uses due to implications of increased climate variability. Development inherently threatens ecological resilience as fragmentation of large tracts of land break connective systems required for natural structural viability. Between 1980 and 2005, approximately 23.8 million acres of the 26 million acre Northern New England Forest region changed ownership (Fidel, 2008). In Vermont, many towns were originally built along rivers during a time when hydropower was the main energy source. Today, historic downtown villages are continually threatened by increases in flooding events. Vermont's strong agricultural economy has also shaped its landscapes and land use configurations. Over 20% of Vermont's landscape is classified for agricultural uses, where humans have large impacts, such as changed natural meanders of rivers. Figure 3.1 shows the increase in disaster declarations from 1962 – 2011 with an upward trend showing significant increase in the last five years. The upward trend is

Figure *3.2*: *Channelization of Mad River in Waitsfield, VT, showing change in river pathway in blue from 1973 – 2004.*

attributable to an increase in storm events and continuing development in vulnerable areas (Johnson, 2012).

Box 3.1 *Media coverage on extreme storms*

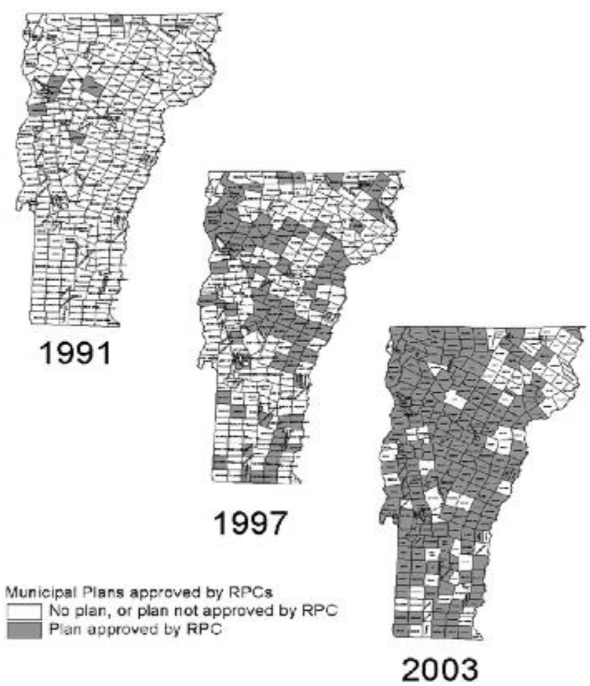
The Rutland Department of Public Works Commissioner, Jeff Wennberg, said after a severe storm with golf ball size hail that caused flooding in Rutland on May 27, 2014

"In a six-year period we've had six storms that were deemed 10-yr storms or worse, and Irene was a 500-year storm. Our storm water system just wasn't built for this level of intense storms."

--*Rutland Herald*, May 28, 2014

1.2 River Channelization: Channelization of rivers in Vermont is one of many examples of how human systems have affected the natural stability of natural systems making them more vulnerable to climate change. Channelization is the process of stopping a river's movement to protect private investments and public infrastructure (Kline and Cahoon, 2010). The negative impact of channelization is a process that increases river slope and velocity which subsequently allows for greater power to dislodge or move sediment and debris along the river bed, especially when flow is high. The resulting effect is a river with much greater capacity to erode and transport hazardous levels of debris during flooding events. Bank armoring is often part of the channelization process which involves excavation of sediment beds, adding to negative impacts. Channelization typically depletes natural habitat, threatens water quality and inhibits the natural process of vital floodplain development (floodplains are necessary for water storage in times of increased water levels). The VT Agency of Natural Resources, through the Department of Environmental Conservation's Rivers Program, has worked with various watershed groups and municipalities to complete over 145 assessments of flood vulnerability involving 170 communities across the state. This work is promoting improved planning for land uses that foster flood resilient communities. The continued understanding of river corridor planning will be an asset to communities as state policies increase focus on improving municipal planning to protect vulnerable infrastructure and natural habitats.

Figure 3.3: *Towns with approved Municipal Plans*



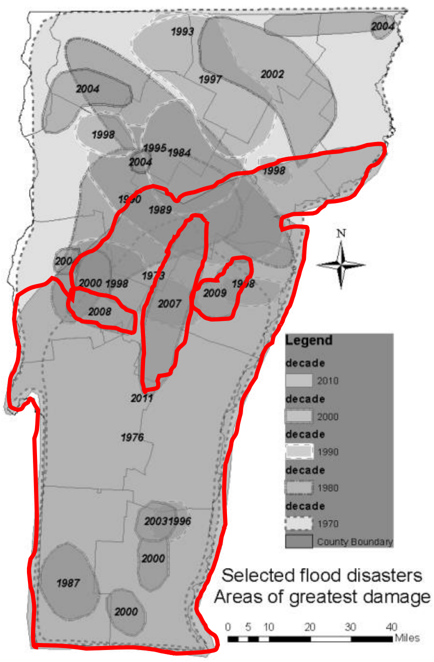


Figure 3.4: *Recurring flooding events in Vermont from 1970 – 2011. Red lines show significant flooding events over last 5 years.*

Extreme weather events require strategic municipal, regional and state planning. Fortunately, there has been an upward trend over the last decade in adoption practices of formal land use planning throughout the state but continued adaptation and expansion of these policies is required as Vermont faces new impacts from climate change. Figure 3.3 shows the increase from 1991 - 2003 in municipalities that have adopted formal town plans, to date, only 9 of Vermont's 251 municipalities have not ever engaged in adopting a formal town plan. As detailed in Chapter 1 on Climate Change Policy, Vermont is taking steps to implement progressive policies that will help to build more resilient communities in the face of climate change. Act 110, passed in February 2011, directed the Secretary of Agency of Natural Resources to establish a river corridor management program and shoreland management program. In 2012, the Legislature passed Act 138, complementing Act 110 in expanding the state's regulatory and technical assistance programs for river and floodplain management. The Rivers Program mentioned above, helps to integrate floodplain management as directed by FEMA's National Floodplain Insurance Program (NFIP) with three major planning elements: fluvial erosion hazard avoidance, river corridor and buffer protection and river science (FEMA NFIP 2014).

*__1.3 Flooding__*__:__ Climate models show increased projections of flood events in many locations across the country due to increased precipitation falling in single or prolonged events. Vermont has seen recent trends that support these projections. There have been recorded increases in stream flow and projections for earlier thaw dates in the winter and more percentage of precipitation falling as rain rather than snow, all of which increase potential for spring flooding and heightened water table levels Figure 3.4 shows the recurrence of flooding events throughout Vermont from the early 1970's through 2011. The map also illustrates how floods are impacting the whole state at one time or another. Highlighted red lines mark the severe recurring flooding over the last 5 years (Betts, 2011).

1.4 Disaster Declarations:

Communities will become more dependent on emergency management systems as climate change perpetuates increased damaging storm events. Between 2007 and 2011, FEMA made 11 disaster declarations in the State of Vermont, mostly due to intense precipitation (ISC, 2013). Every single county in the State of Vermont announced FEMA disaster declarations in response to flooding events in 2011. Communities will need to work to better understand the hazards they potentially face and how to respond appropriately in the short term and adapt efficiently in the long term. Vermont's rural and fragmented communities pose additional challenges for implementation of effective emergency response systems. Our ability to remain connected, technologically and responsively through emergency response will determine the success of enhanced resilience to a changing climate. Local governments adopt Emergency Operations Plans (EOP) on a town-specific basis. Additionally, at the State level, the Vermont Department of Emergency Management and Homeland Security (DEMHS) has its own EOP. Many communities have an emergency management director, but this is typically a volunteer position. This person will serve as the command and control officer in the event of an emergency. There is also regional support through 10 local emergency planning committees located throughout Vermont that help to support emergency preparedness (ISC, 2013). The current system is set up such that in the event of an emergency, all efforts are coordinated through the State Emergency Operations Centers (SEOC) which are located in Waterbury, VT. There are potential vulnerabilities in a system that relies on individuals or on one specific location for response if disaster events cut communication from these key people and places.

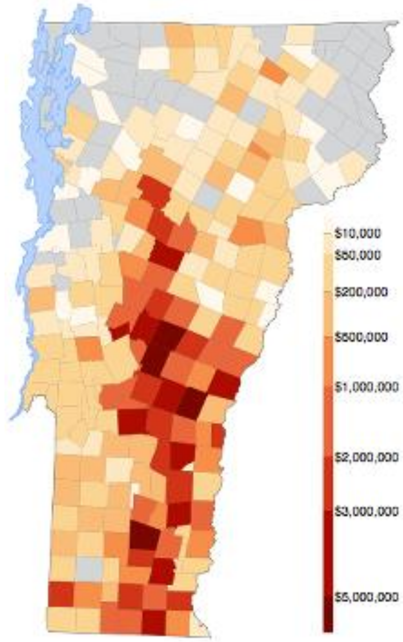


Figure 3.5*: VPR Mapping the Money Project illustrating state federal aid support received by town for damages incurred by Tropical Storm Irene, 2011.*

1.5 Hazard Mitigation Planning:

Hazard mitigation planning takes place both at the municipal and state levels. The State of Vermont has a Hazard Mitigation Plan (HMP) that incorporates statewide strategy for all types of natural hazards. This plan was redrafted in May 2013 through the Department of Public Safety's Division of Emergency Management and Homeland Security (DEMHS). The plan includes risk and vulnerability assessment of natural, atmospheric and technological hazards that pose potential threat to the citizens of Vermont. It outlines a mitigation strategy and with goals and action items for continued resiliency to future threats. The plan also communicates a coordination strategy for local mitigation planning and integration. As is required by the Federal Emergency Management Association (FEMA), all Hazard Mitigation Plans must also detail a planning process and the steps for continued maintenance of the plan to monitor and evaluate its success and procedures (VEM, 2013). It is important for towns to officially adopt HMPs in order to be eligible for certain federal recovery support and grants for rebuilding or even pre-disaster planning projects. With continued projections of extreme weather events, adaptation may require that we build upon and expand the current systems so that Vermont communities are more aptly prepared. Strategies could include building up at the local level or expansion from the top down with state leadership. Some Vermont agencies are engaged in plans to create a system that calls on qualified reservists in the event of an emergency. The State is working to support Hazard Mitigation Planning through ACCD's Strong Communities program and ANR's Flood work (ACCD, 2013; ANR, 2013). Towns across Vermont are working to create and adopt HMPs, particularly those that have experienced damages.

2. Communities across the state are undergoing adaptation planning.

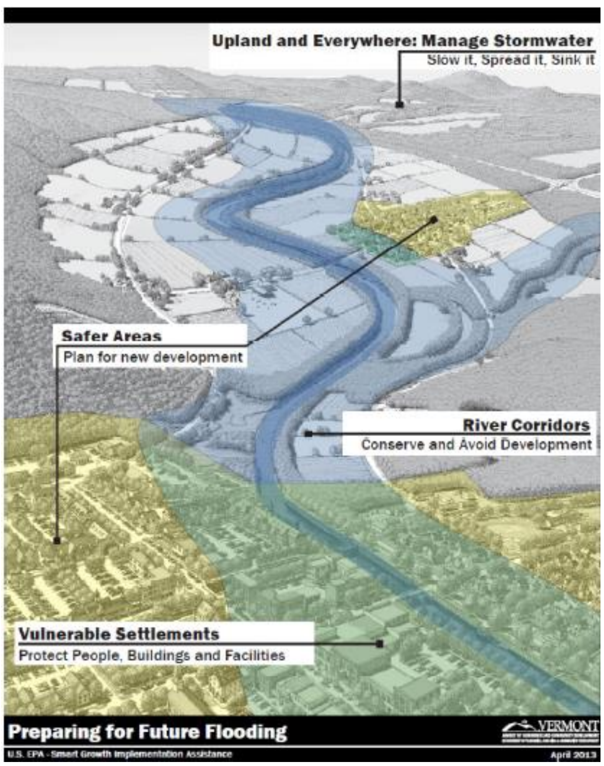


Figure 3.6: *Four recommendations for smart growth development to plan for resiliency to future flooding in Vermont. Credit: State of Vermont*

Climate change impacts will continue to require adaptation planning on local, regional and state levels. Regional and watershed based planning perspectives will become more crucial as the State works to protect its important economies and communities. Land use planning must acknowledge climate change impacts via smart growth development strategies, improved stormwater management and flood resilient planning.

<u>2.1 Smart Growth Development</u>:

The processes of development planning will continue to impact our ability to become more resilient to climate change. Smart growth development focuses largely on better development and use through updated planning related to water supplies, sewage treatment and transportation in town centers and villages to allow for more efficient use of land and energy. Efficient use implies improved adaptive capacity as well as mitigation of contributions to climate change. The Agency of Commerce and Community Development recently released a report with recommendations for smart growth development through an EPA-supported partnership for sustainable communities working with the Department of Transportation and Department of Housing and Urban Development. The project selected one community in central Vermont to analyze and worked with the local planning district to put out the final strategies for preparing for future flooding that are now being communicated to other communities around the state. The recommendations for adaptation focus on four primary areas and give suggestions for action: (1) In River Corridors: *Conserve land and avoid development in particularly vulnerable areas such as floodplains and river corridors*, (2) In Vulnerable Settlements: *Where development already exists in vulnerable areas, protect people, buildings, and facilities to reduce future flooding risk,* (3) Safer Areas: *Plan for and encourage new development in areas that are less vulnerable to future flooding events* and (4) Upland and Everywhere: Implement stormwater management techniques to slow, spread and sink floodwater. The Vermont Downtown Action Team is also working with ACCD to build plans to strengthen economic vitality of seven downtown villages that were impacted by heavy flooding as a result of 2011's Tropical Storm Irene (ACCD, 2012a).

2.2 Act 16 Flood Resilient Planning (ANR Strong Communities Program):

In July 2013, the Vermont Legislature passed Act 16, regarding municipal and regional planning and flood resilience. The act addresses two components; that all municipal and regional plans will include a flood resilience element and that accessory dwelling units may be regulated in hazard areas. The purpose and goals are as follows:

§4302. PURPOSE; GOALS
(14) To encourage flood resilient communities.
(A) New development in identified flood hazard, fluvial erosion, and river corridor protection areas should be avoided. If new development is to be built in such areas, it should not exacerbate flooding and fluvial erosion.
(B) The protection and restoration of floodplains and upland forested areas that attenuate and moderate flooding and fluvial erosion should be encouraged.
(C) Flood emergency preparedness and response planning should be encouraged.

The legislation goes into effect July 1, 2014. Towns that do not comply will not be eligible for certain funding and grant opportunities. Additionally, in order to qualify for the National Flood Insurance Program (NFIP), towns must comply with federal guidelines that this act acknowledges and seeks to build upon. The plan explicitly details the requirement of state support for towns and regional planning commissions to fulfill these requirements. Through the Resilient Communities program under the Agency of Natural Resources, the department is working to help provide technical assistance and outreach. A website has been developed that provides information and communication tools for planners, and a more complex website through the Focus on Floods Initiative is planned to be released early next year (ANR, 2013). The Agency is also assisting municipalities in their efforts to adopt flood resilience plans through supporting a river corridor mapping program through the Department of Environmental Conservation. This program is working to produce maps that identify floodplains, river corridors, land adjacent to streams, wetlands, and important upland forest areas.

In Vermont, many damages occur outside of floodplains, nonetheless, the National Flood Insurance Program (NFIP) delineates boundaries based on floodplain maps and municipalities that seek financial support through the NFIP must follow these maps in their planning processes. Currently, almost 90% of Vermont's 251 municipalities participate in the NFIP. Additionally, around 17% have adopted regulations that protect river corridors or floodplains. Moving in the right direction, Vermont towns will need to continue to adopt these kinds of regulations to respond to future threat of projected reoccurring flooding events.

2.3 Stormwater Management Strategies:

Increases in precipitation will require improved statewide stormwater management systems. Strategic stormwater management will improve our ability to respond to the threats of extreme weather events. Climate change forecasts of changes in precipitation make Vermont particularly vulnerable to flooding and issues related to water quality. This vulnerability is born from the state's geographical structure of mountainous valleys with many of the state's downtown villages and agricultural lands located in correlating floodplains. Stormwater management has not historically been planned through strong regional collaboration which is crucial in order to build resilience through watersheds.

There are 18 different watersheds in Vermont. Currently, the State has no comprehensive stormwater management system that aligns with watershed jurisdiction. Rather, the Vermont Department of Environmental Conservation Stormwater Program is directed through a permit structure for new development, redevelopment and expansion projects. Permits are issued separately for runoff from impervious surfaces, construction sites and industrial sites. The primary goal of the State Stormwater Permit Program is to regulate discharges (runoff) from impervious surfaces (ISC, 2013). While Act 16's new legislation does not explicitly detail adaptation planning or updated regulations around stormwater management, it does directly link the importance of protecting intact forested landscapes as providers of important flood regulating services. Protection of natural lands that attenuate flood waters during increased heavy precipitation events will be a crucial step for Vermont in building resilience to the impacts of changes in precipitation.

With changes in climate, Vermont will need to implement strategies outside of regulation and inclusive of adaptation. Stormwater planning will require both urban system adaptations and large green infrastructure planning through methods such as wetland conservation or protection of valuable upland forestlands. Urban stormwater management includes smaller scale green infrastructure projects such as city rain gardens or underground rain catch systems.

The State Stormwater Program outlines Water Quality Practices that:

- can capture and treat the full water quality volume (WQv),
- are capable of removing approximately 80% total suspended solids (TSS) and 40% total phosphorus (TP) removal, and
- have acceptable performance and longevity in the field.

Table 3.1 *Water Quality Practices* (Vermont Stormwater management manual)

Water Quality Practice	Description of practice
Stormwater Ponds	Practices that have a combination of permanent pool and extended detention capable of treating the WQv.
Stormwater Wetlands	Practices that include significant shallow marsh areas, and may also incorporate small permanent pools or extended detention storage to achieve the full WQv.
Infiltration Practices	Practices that capture and temporarily store the WQv before allowing it to infiltrate into the soil.
Filtering Practices	Practices that capture and temporarily store the WQv and pass it through a filter bed of sand, organic matter, soil, or other media.
Open Channel Practices	Practices explicitly designed to capture and treat the full WQv within dry or wet cells formed by check dams or other means.

3. The infrastructure systems of Vermont's communities are highly vulnerable to climate change. A mountainous, rural geography combined with small rural communities with limited transportation routes and communication systems elevate this vulnerability. Antiquated water infrastructure and aging built-infrastructure pose additional challenges, particularly given limited economic resources available for adaptation.

Climate change has had and will continue to have a significant impact on infrastructure systems in Vermont. With increasing stream flows, Vermont's roads, bridges, dams and water systems are all at increased risk. Transportation infrastructure tends to mirror river corridors and many roads are in vulnerable valley regions where towns are often located. Vermont's mountainous geography with deep river valleys perpetuates water runoff risks.

Climate models show a continuous increasing trend in precipitation levels in Vermont. Figure 3.11, provided by the National Weather Service, shows historical data tracking precipitation levels from 1910 – 2010 measured in the months of December and January. The blue line shows this increasing trend through time. With these projected increases in precipitation, both in the form of snow and rain, we also expect to see increases in extreme weather events that result in flooding events or inundation of land in floodplains. Water infrastructure needs to assure that we will be able to supply clean drinking water. Transportation infrastructure will need to be adapted to withstand stream erosions and flooding events. Built infrastructure will need to be reinforced, particularly in floodplains and fluvial erosion hazard areas. Complicating this in

Vermont is that many infrastructure systems are aging and in serious need of repair regardless of climate change impacts.

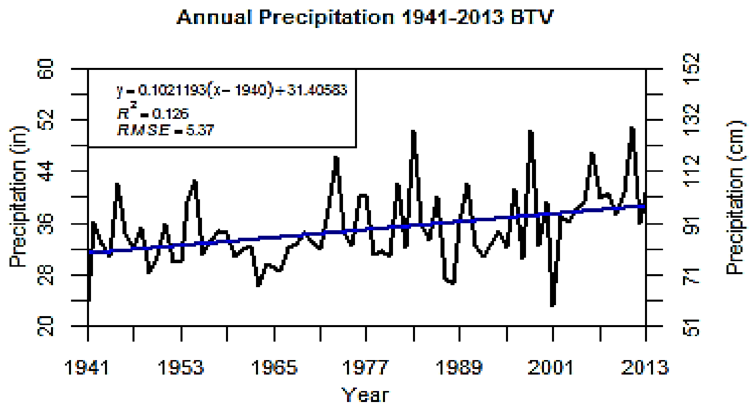


Figure 3.11 *Change in annual precipitation from 1941-2013 (BTV station). See Chapter 1.*

3.1 Water infrastructure: Restoring clean water to the state will require an estimated investment of $156 million per year for ten years (Dolan, 2013). Water infrastructure throughout Vermont is antiquated and under- prepared for both isolated flooding and larger flood events both with regard to wastewater and drinking water management. The Vermont Section of the American Society of Civil Engineers released a report card for Vermont's infrastructure in February 2012 that evaluated Vermont's roads, bridges, dams, municipal drinking water and municipal wastewater systems. The grades ranged from C to D- in all five categories. In order to sustain current functioning and be able to respond to potential damages from an increase in extreme weather events, Vermont needs to invest in upgrading and adapting these systems to be more resilient. A subsequent report was published for the Vermont General Assembly in Accordance with Act 138 passed in 2012. The report, titled, Water Quality Remediation, Implementation and Funding Report was released in January 2013. The report details costs and actions for priority improvements. The summarized estimate of restoring clean water to the state is $156 million per year for ten years. Compounding the challenge of costs needed to update our water infrastructure is the issue of supply networks across rural communities and the location of many valley communities that are located in floodplains. The state has a total of 1,367 public water systems and nearly 90 percent serve less than 500 people (ANR, 2011). Many of the municipal systems are run by limited staff capacity and lack adequate inventory of system structure and condition. While the State provides support through low- interest loans through its Drinking Water and Wastewater State Revolving Funds, and communities can use municipal bonds to fund projects, there is an overwhelming gap in the funding needed to become adequately prepared for events such as extreme flooding. Some communities have been engaged in safeguarding water infrastructure to be more prepared for flooding including construction of backup well heads or placing bypass pipe systems above the 100 year floodplain elevation. The town of Waterbury has received state assistance in developing an asset management plan to prioritize replacement of infrastructure that is most vulnerable to failure. Communities will need to continue to better understand the needs of protecting groundwater and safeguarding or repairing wastewater systems as weather events will continue to impact these systems.

3.2 Transportation Infrastructure

Much like our water infrastructure, the State's transportation system will require substantial investments. Figure 3.12 shows a report card evaluation completed in 2011 by the American Society of Civil Engineers Vermont Chapter. The report card details that roads are in poor condition with a grade of a D+.

Flooding poses the greatest risk to transportation infrastructure, but more acute erosion, extreme heat events and winter storms will also create damages. The damages from

2011 Report Card For Vermont's Infrastructure Issue Brief Summary

SUBJECT	2009 NATIONAL GRADE	2011 VERMONT GRADE	COMMENTS
Bridges	C	C-	Bridge funding continues to fall below levels necessary to maintain the existing infrastructure. Successfully and efficiently addressing Vermont's bridge infrastructure will require a long-term, comprehensive strategy, including identifying potential financing methods and investment requirements. Increasing investment levels now will improve the condition and functionality of Vermont's bridges and reduce the required future investment.
Dams	D	C	Vermont has 1,150 dams on its state inventory and 199 (17%) of those structures are classified as high or significant-hazard-potential. Vermont's Dam Safety Program is understaffed and depends on a voluntary action by dam owners or a time-consuming State process for correcting safety deficiencies. The Vermont Dam Safety Program relies heavily on educating dam owners of safety risks to motivate repairs. Rehabilitation of poor condition dams is estimated to cost $17 million. The majority of Vermont dams are the responsibility of private landowners that have limited resources and willingness to invest in maintenance and repairs.
Drinking Water	D-	C-	Many of the existing facilities and subsurface infrastructure across the state are at or beyond their design life. With an increasing population and higher effluent standards the current levels of funding are not adequate to keep pace with future need.
Wastewater	D-	D+	Many of the existing facilities and subsurface infrastructure across the state are at or beyond their design life. With an increasing population and higher effluent standards the current levels of funding are not adequate to keep pace with future need.
Roads	D-	D+	Highway investment needs in Vermont mirror that of the rest of the country and are defined by weak revenues, rising material costs, and aging infrastructure.

A = Exceptional
B = Good
C = Fair
D = Poor
F = Inadequate

Categories were evaluated on the based on existing conditions, capacity, operations & maintenance, public safety, risk and current and projected levels of funding.

Figure 3.12 *Report card for Vermont's infrastructure by American Society of Civil Engineers Vermont Chapter.*

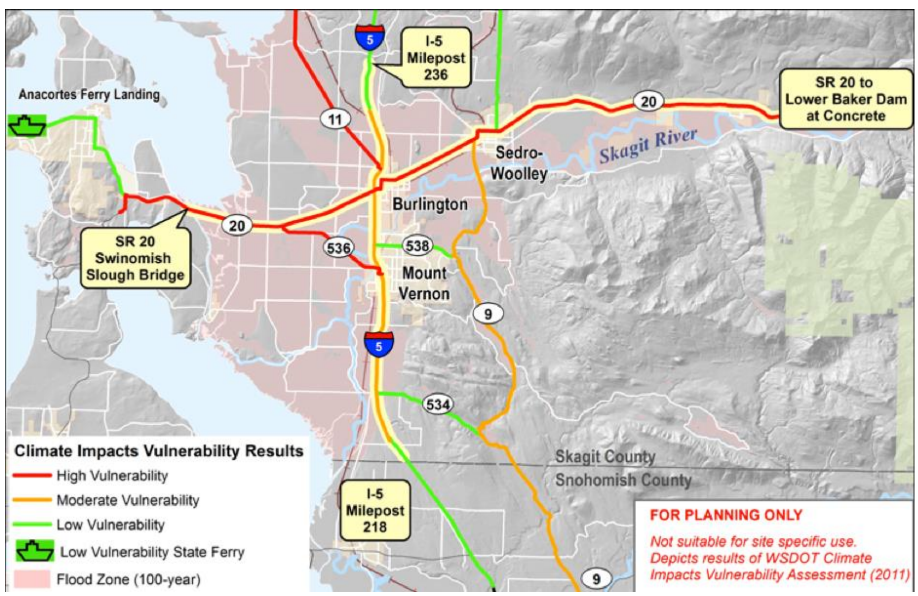


Figure 3.13 *Skagit River Basin climate-risk study results showing vulnerability levels to flood and sea level rise risks of climate change projections in Western Washington State. Credit: Washington Department of Transportation.*

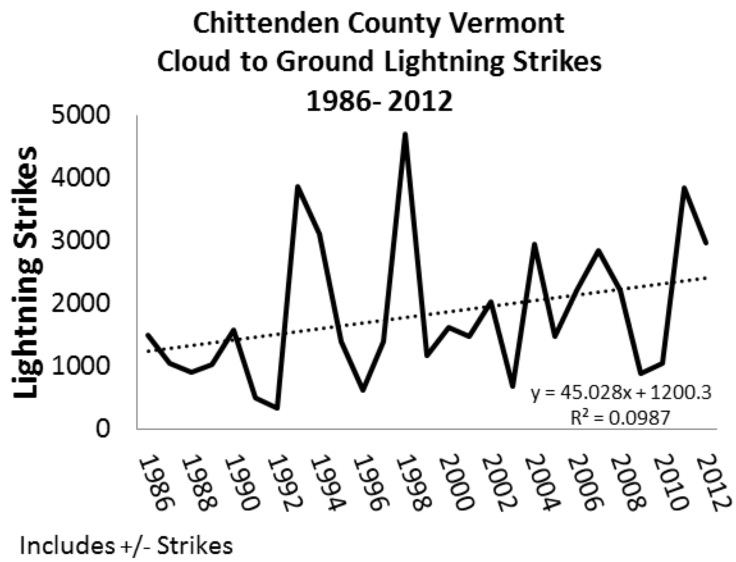


Figure 3.14. *Increasing lightning strikes indicate increasing intensity of electrical storms (NWS 2014).*

Tropical Storm Irene's flooding totaled over $200 million to Vermont's State Highway system affecting over 500 miles of roads and 200 bridges throughout the state. Again, Vermont's rural nature compounds the complexity of maintaining a strong transportation network. Over 2,884 miles of class 1 & 2 roads and 8,531 miles of class 3 roads are under local jurisdiction, landing a high level of financial responsibility on already burdened town budgets (ISC, 2013). It will be important to identify high risk areas both based on current condition or roads, bridges, culverts and dams combined with level of threat of flooding or other weather events. Washington State conducted a Risk Based Asset Management analysis that determined a statewide picture of the areas with greatest vulnerabilities producing a map that identifies prioritization areas for repairs or upgrades based on threats from sea level rise projections. The Washington Department of Transportation was able to conduct this study through a matching grant program with the Federal Highway Administration. The Vermont Agency of Transportation (VTrans) has been engaged in work with the Agency of Natural Resources to build long-term resilience through "Flood Resiliency Training Programs" to educate stakeholders on best management practices. Additionally, VTrans has been working to develop Transportation Resiliency Plans outlined on a watershed basis to identify high risk areas, similar to the work of a risk based asset management program like the example in Washington State (Johnson, 2012). Strong support for these types of programs must continue as we work to adapt to a changing climate.

In 2008, VTrans published a Climate Change Action Plan, recognizing the need to leverage the transportation sector's capacity to effect change in levels of GHG emissions in Vermont with transportation accounting for 44 percent of Vermont's overall GHG emissions. The Climate Change Action Plan has three primary focus areas; (1) reducing GHG emissions from the transportation sector, (2) protecting Vermont's transportation infrastructure from the threats of climate change, and (3) reducing Vtrans' operational impacts on climate change. Focus in response to severe damages to infrastructure over the last couple of years as a result of both widespread and isolated flooding has shifted towards research to identify climate related thresholds to Vermont's transportation infrastructure, a process that aims to help guide decision making for investments and planning. The state and local towns are recognizing an increasing need to upsize infrastructure to accommodate geomorphic conditions and stream flows that are out of equilibrium. In the last ten years, ANR has worked with communities and assessed more than 8,000 of Vermont's 23,000 river and stream miles. This work reveals that over 75 percent of assessed river miles are out of equilibrium, rendering them as unstable (ANR, 2011). The instability of river corridors threaten the environmental health of ecosystems and greatly increase risk for impact from storm events to our transportation system (Kline and Cahoon, 2010). In combination with assessing rivers, attention is being directed at bolstering asset inventory data related to transportation and water infrastructure both at the municipal and state level. In the town of Sharon, the river corridor plan assessment completed in 2010 prepared under contract by the Two Rivers-Ottauquechee Regional Commission reports findings identifying over 30 percent of culverts in the White River Watershed as incompatible with existing geomorphic stability (Fitzgerald Environmental Associates, LLC, 2010). With climate projections for increased extreme storm events, these vulnerability and risk assessment inventories are a valuable asset and will collectively support building resilient systems in Vermont.

4. **Resilient communities will engage in hazard mitigation planning to respond to increased emergency response needs from vulnerable populations, rural communities and areas that have been exposed to extreme weather events, particularly flooding. The State will need to continue to lead in hazard mitigation planning and provision of guidance and support to local communities.**

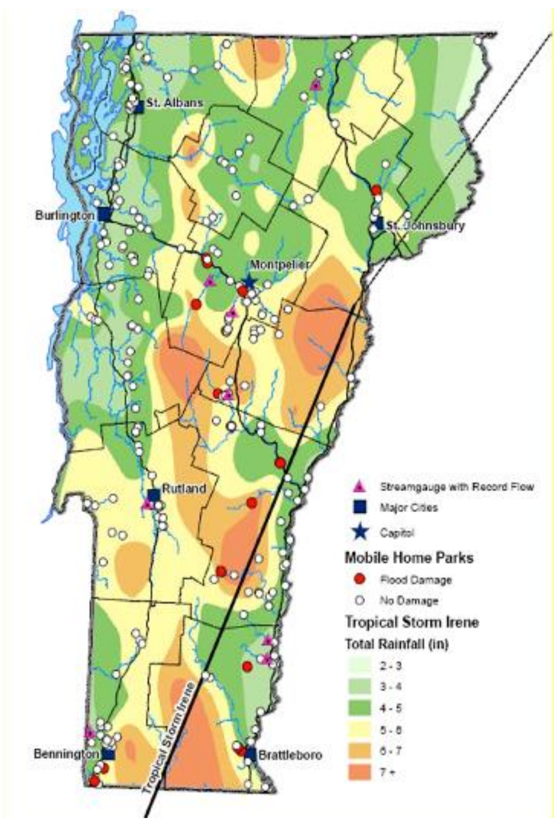


Figure 3.15*: Mobile Home Parks within Flood Damage Regions*

4.1 Communications infrastructure: Telecom

Increases in lightning storms and electrical charge of lightning threatens communications infrastructure. Climate models show projections of increasing cloud to ground lightning strikes. With the projected increase in heavy storms there is a potential increase in risk of destruction and damages to our telecom and communications infrastructure. Figure 3.14 shows the increasing trend in lighting strikes since 1986 along the dotted line. Increasing trends in electrical storms will put our communication systems out of order during times we need them most to communicate emergency response.

4.2 Human Well-being, looking at elderly, impoverished, foreign/non-native populations

The rural nature of Vermont poses increased threats from climate change. Communications and transportation systems are vulnerable to severe weather events, which can cut off individual households or entire towns from support that they depend on. Due to the widespread distance between households, in the event of a disaster response protocol, communication of evacuation plans or information about aid locations are more challenging. Many towns have volunteer fire departments or municipal positions and depend on informal emergency management communication plans.

Lower-income residents are at higher risk of impacts from flooding, particularly those residing in mobile homes (which represent almost 7% of all housing in Vermont). Mobile homes represent vulnerabilities in that there is a high level of home ownership (87% of residents owning their mobile homes) and many mobile homes were built before 1970. This means that losses from damage are more impactful for owners and the aging infrastructure is at higher risk for damage. Furthermore, over 80% of these residents fall into HUD (Housing and Urban Development) low Area Median Income (AMI). Perhaps the greatest vulnerability is that many of the state's mobile home parks are located in floodplains. More than 20% of mobile home parks have at least one lot located in a flood hazard area and just under 32% of parks have a portion of property in the floodplain. During Tropical Storm Irene's flooding of 2011, mobile homes sustained disproportionate damages. While mobile homes account for 7% of the state's housing stock, 15% of damages to residences reported across the state were mobile homes (Baker, 2012). Figure 3.15 depicts a map of the state of Vermont with locations of mobile home parks. Notably, most mobile home parks in Vermont are located in floodplains. The red dots indicate the homes that were damaged by Tropical Storm Irene (Baker, 2012).

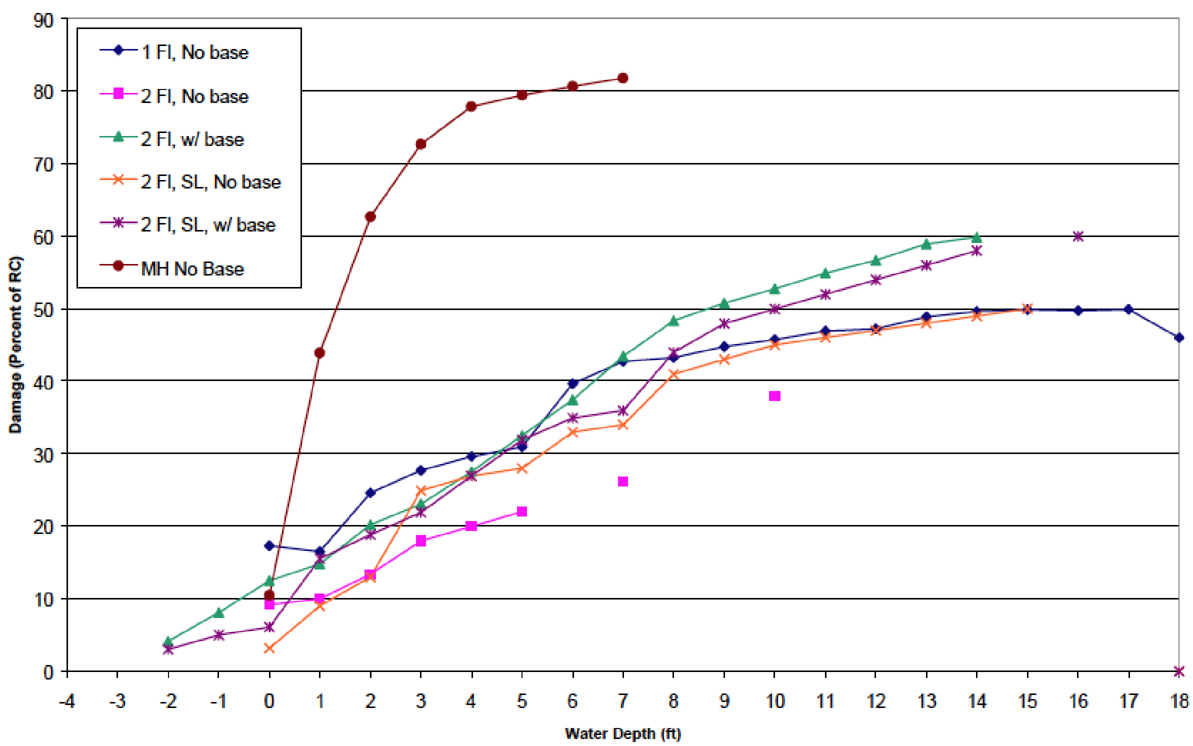


Figure 3.16 *Imbalanced damages to mobile homes, FIA Credibility-Weighted Building Depth-Damage Curves as of 12/31/1998.*

Figure 3.16 shows six Federal Insurance Administration (FIA) credibility-weighted damage functions. The six categories, in order of the key below, are one floor, no basement, two floors, no basement, two or more floors with basement, split level no basement, split level with basement and mobile home. As is evident, mobile home damage is significantly higher than other categories. These numbers are based on data from damage claims for the period of 1978-1998. The loss figures include both structure and content losses through the National Flood Insurance Program recorded claims (HAZUS Manual).

5. Adaptation and Mitigation

The current work to build resilience for vulnerable populations includes both a community development element as well as specific capacity building for improving structures via housing retrofits, energy efficiency updates, alternative designs and in some cases relocation. The work associated with policies such as Act 16 will help to protect the floodplains that mobile home parks are often located near or in and efforts for improved river corridor management help to build resilience for these communities. The Vermont Planners Association is currently engaged in the promotion of Climate Resilience planning elements in town and regional plans. The association has membership of about 150 professional planners, landscape architects, engineers and planning consultants across the state. While this effort has not been taken up by the legislature yet, some communities are addressing climate resilience in their plan updates. In Vermont, towns are required to update plans every five years. Building resilience to climate change impacts will become more effective as broader acceptance of these standards are adopted by communities during planning updates.

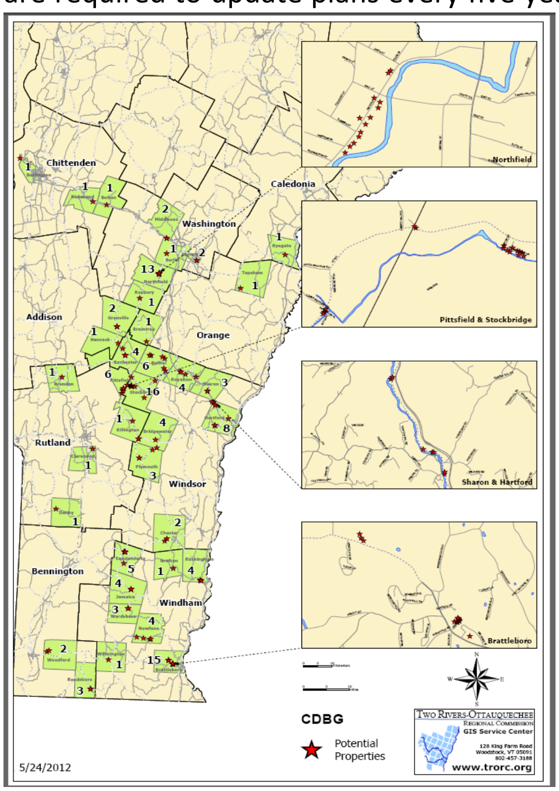


Figure 3.17: Pending FEMA HMGP buyouts as of May 2012. Retrieved from CDBG Action Plan.

The Vermont Agency of Commerce and Community Development's (ACCD) Strong Communities program is working to provide technical assistance and education on how communities can work to become more resilient through a "Plan Today for Tomorrow's Flood" initiative. The ACCD webpage houses information on grant opportunities, state and federal funding support and a variety of public outreach resources. Focus is on disaster recovery and long term resiliency planning in order to be more prepared for future natural disaster events.

Federal funding is available through the Hazard Mitigation Grant Program (HMGP) for purchasing properties located in flood prone hazard zones. Federal funding is offered to qualifying properties at 75% with local community match at 25%. Following the events of TS Irene, the State of Vermont has now committed to support the Vermont Housing and Conservation Board in working with the HMGP funding to help communities finance the 25% cost through a Community Development Block Grant Disaster Recovery (CDGB-DR) Program. As of July, 2012, 92 residences located in floodplains had been approved by the State and submitted for FEMA review for buyouts. These are all cases of voluntary action by property owners. Figure 3.17 illustrates the location of the pending buyouts throughout the state. Continued funding and focus will need to support these efforts to promote greater resilience in communities throughout the state. As of 2012, the total estimated unmet housing need was about $19.5 million (ACCD, 2012b).

Additional adaptation planning for building community resilience in Vermont has been through a Community Recovery Partnership launched by Governor Shumlin in response to damages from Irene. The partnerships have brought State agencies, local and regional officials, nonprofits, volunteers, local business owners, State floodplain managers and infrastructure experts together to plan for more long-term solutions for recovery efforts that lay groundwork for rebuilding stronger. The partnership process included convening of meetings in 45 towns across the State drawing over 500 participants. Many of the actions and continued planning happening at the town and regional planning levels were informed by these meetings and continue to build off of the principles set regarding planning, response and recovery in these initial gatherings. The State is now focused on long-term planning working across agencies to set policies that support continued achievements towards resilience to impacts from climate change through land use, regional planning, downtown redevelopments, housing, transportation, environment and economic development (ACCD, 2012c). Individual communities are now engaging in writing Long-Term Community Recovery Plans; Wilmington and Waterbury are two examples with completed plans.

5. 1 Case Study: Lessons from early adopters

Figure 3.18: *Resilient Communities Scorecard (VNRC)*

Scoring	Suggested Steps for Building Resilience
31-36 Resilient Community	• Contact your RPC about **brownfields** assessment and redevelopment. • Ensure that planned **public buildings** are located in or adjacent to the town center.
22-30 In Transition	• Look into **state designation programs**. • Make sure **zoning** actual creates a distinct, compact town center surrounded by countryside.
12-21 Needs Your Attention!	• Define a **town center** in your town plan and/or zoning. • Revisit policies on **sewer and water service areas** (definitions and extensions).

Resilient Communities Scorecard – *Vermont Natural Resources Council (VNRC)*

In February 2013, the Vermont Natural Resources Council released a tool for towns to use in building more resilient communities; a scorecard where planners, community members, selectboards and conservation and planning commissions can ask questions about their town. Using the guidance from VNRC's scorecard, users can ascertain a score that distinguishes a town's level of resilience into three categories:

Smart Growth, In Transition, Needs Your Attention.

The scorecard document is framed by 12 checklists that cover topics ranging from energy conservation to land use planning for flood zoning to effective, smart business development. Each section starts with a help box that outlines tips to help assure accurate scoring. These boxes give specific information on how to consider the questions being asked in that particular section. After reading the list of questions and selecting the response that best fits the town's current state, the user can add up their points to receive a certain score of resilience. The success of this tool is in large part attributed to the clear and direct action steps it provides for communities to take in response to their scores based off of their unique needs or characteristics. The box to the right gives the example action steps suggested to promote vibrant communities by directing business and housing development toward compact, mixed-use town centers, at a scale of growth that fits the community and the region.

Throughout the report there are additional text boxes that provide definitions of resilience 'buzz' words such as 'open space': a term used to describe land that is not occupied by structures, buildings, roads, rights-of way, and parking lots, and which has been designated, either through an easement or permit restriction, to remain undeveloped. You might also find the difference defined between inundation hazards and erosion hazards. Furthermore, inspiring photos and quotes from influential planners and leaders of sectors pertaining to the various scorecard sections fill the margins, such as:

"At its most basic level resilience is about building relationships, getting people talking, connecting and creating something bigger than an individual might be able to do on his or her own. A resilient community is an empowered and collaborative network of people that organically adapts to the needs of its parts through the strength of the whole."

- ***Joshua Schwartz, Mad River Planning District Director***

The scorecard shows tremendous potential in its ability to help Vermont's local decision makers address the emerging challenges of incremental and scattered development, rising energy costs, and climate change. By evaluating strengths and weaknesses VNRC hopes to help communities promote vitality of downtowns and villages, address rising energy costs, build community resilience, reduce transportation costs, improve public health and adapt to climate change.

More information on VNRC's Resilient Communities Scorecard and the full document can be found at: http://vnrc.org/resources/community-planning-toolbox/tools/vermont-smart-growth-score-card/

Box 3.2 Mad River Valley – Long-term Resilience Planning in Action

The Mad River Valley of Vermont (MRV), a community of four towns within the Mad River watershed, has experienced devastating flooding events over the last fifteen years resulting in detrimental damages to farm and forestland, local businesses and residents, and wildlife habitats. The most recent flooding event in the Mad River Valley was in August 2011 from Tropical Storm Irene. According to the Mad River Valley Planning District, damage to roads and bridges alone in Vermont exceeded $175 million. Locally in the MRV, 1300 acres of crops were destroyed and 191 properties were damaged, in response FEMA paid out more than $36 million in aid to local residents (Noel et al., 2012). While the agricultural and recreational economies are crucial to the area, the associated land development to support these industries has led to increased sediment loading, bank erosion, river incision and deforestation/forest fragmentation.

Figure 3. 19. *Sediment deposits from flooding. Photo Credit: Lars Gange & Mansfield Heliflight*

The Mad River Valley Planning District (MRVPD) was created in 1985 as a planning body focused on identifying the agricultural, scenic, natural and recreational assets of the Valley (MRVPD, 2013). As pressure increased to leverage conservation as a tool to protect the area's valuable watershed, the MRVPD, the Vermont Land Trust and The Friends of the Mad River (FOMR) created the Mad River Conservation Partnership. Along with the completion of a multitude of conservation projects, this partnership has focused on protecting undeveloped tracts of forestland. In total, 47,143 acres and counting have been conserved in the Mad River Watershed throughout the towns of Fayston, Waitsfield, Warren, Moretown and Duxbury.

In response to Tropical Storm Irene, the US Environmental Protection Agency (EPA) Office of Sustainable Communities and the Federal Emergency Management Agency (FEMA) partnered to provide technical assistance to the Mad River Valley through the EPA's Smart Growth Implementation Assistance (SGIA) project. The SGIA project resulted in a report entitled Disaster Recovery and Long-Term Resilience Planning in Vermont, an analysis of how the MRV can reduce its vulnerability to future flooding events. The project identifies erosion hazard areas as crucial in mitigating erosion risk that leads to increased frequency and severity of flooding (FOMR, 2013). The report advises that Hazard Mitigation Plans (HMPs) should explicitly discuss land use tools that can be used to guide future development away from known flood hazard areas. It also discusses adding regulatory audits in town plans inclusive of stream and wetland buffer requirements (EPA, 2013). In the Mad River Valley, 15% of the floodplain is currently conserved land, or 345 acres (VLT, 2013).

Through these strong community partnerships, collaborative governance networks and a deep appreciation for the social, environmental and economic landscape meaningful action is taking place in the MRV. Two of the district's towns, Waitsfield and Warren, have officially adopted fluvial erosion hazard programs that work to prepare and protect the landscape, farms and the downtown villages within the 92,000 acre watershed.

More information on the current and future progress in the Mad River Valley can be found at: http://www.mrvpd.org/.

6. Summary Table Rating Quality of Information

Key Message 1	**Many communities have already been highly impacted by changes in weather and are engaged in processes to respond to climate change related transitions.**
Description of evidence base	Vermont has received over $565 million in federal and state aid for recovery from 2011's Tropical Storm Irene alone. There were 11 FEMA Disaster Declarations between 2007 and 2011 in Vermont. In 2011 alone, every single county in Vermont submitted FEMA disaster declarations.
Assessment of confidence based on evidence	Given the evidence base and remaining uncertainties, confidence is **very high** that communities have been highly impacted by climate change and are responding. Vermont Strong Network http://www.vtstrong.vermont.gov/RESOURCES/RecoveryReports.aspx Resilient Vermont Initiative http://www.iscvt.org/news/toward-a-more-resilient-vermont/

CONFIDENCE LEVEL

Very High	High	Medium	Low
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Key Message 2	Many communities across the state are undergoing adaptation planning. State policies are supporting this planning.
Description of evidence base	• Vermont Agency of Natural Resources Flood Resilience Planning https://outside.vermont.gov/agency/ANR/FloodResilience/Pages • Vermont Act 16 Legislature to promote flood resilient communities • Community Development Grant Block Program • Strong Communities Program through Agency of Commerce and Community Development http://accd.vermont.gov/strong_communities/opportunities/planning/resiliency
Assessment of confidence based on evidence	Given the evidence base and remaining uncertainties, confidence is **very high** that communities are undergoing adaptation planning with the support of state policy.

CONFIDENCE LEVEL

Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Key Message 3	Resilient communities will also need to engage in hazard mitigation planning to respond to increased emergency response and disaster recovery needs from vulnerable populations, rural communities and areas that have been exposed to extreme weather events, particularly flooding in the state of Vermont. Vermont is already engaged in taking action.
Description of evidence base	• Updated State Hazard Mitigation Plan, (2) Community Development Block Grant Program, (3) Long Term Community Recovery Plans, Wilmington and Waterbury.

- Wilmington: http://www.vtstrong.vermont.gov/Portals/0/Documents/Wilmington%20Plan__FNL.pdf
- Waterbury:

http://www.waterburyvt.com/fileadmin/files/Town_clerk_files/LTCR_AAR_11_11_13.pdf

Assessment of confidence based on evidence	Given the evidence base and remaining uncertainties, confidence is **very high** that communities need to engage in hazard mitigation planning.

CONFIDENCE LEVEL

Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Key Message 4	Antiquated water infrastructure, aging transportation systems and vulnerable built infrastructure pose additional challenges in response to limited economic capacity for adaptation.
Description of evidence base	• Report Card on Vermont's Infrastructure: Over the next 20 years an estimated $453 million in drinking water infrastructure needs and $218 million in wastewater improvement needs. http://www.infrastructurereportcard.org/vermont/vermont-overview/ • Irene Flooding Damages: 531 miles of State highway closed, 34 bridges closed, 963 town culverts damaged, 277 town bridges damaged or destroyed, 2,260 town highway segments damaged, 200 state railroad miles impassable.

	• Over 75 percent of assessed river miles in Vermont are unstable posing increased vulnerabilities for adjacent transportation and infrastructure systems.
Assessment of confidence based on evidence	Given the evidence base and remaining uncertainties, confidence is **very high** that infrastructure is vulnerable and economically limiting our adaptation to climate change.

CONFIDENCE LEVEL

Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Supporting Work

Ned Swanberg, Department of Environmental Conservation, Vermont Agency of Natural Resources

Chapter 4: Energy

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Key Messages

- **Energy efficiency and conservation are key components of Vermont's goal of 90% renewable energy sources by 2050. Understanding mechanisms that can increase energy efficiency and conservation behaviors are central to this challenge. Policy decisions that leverage an understanding of behavior change could profoundly support this mitigation effort.**

- **Adaptation through the use of renewable, local energy sources will be increasingly important as extreme weather events increase and threaten fossil fuel energy supplies. In addition, reducing reliance on international energy supplies increases Vermont's energy security. Current policies in Vermont create opportunities for local, renewable energy development.**

- **Increased risk of major storm events in Vermont will threaten energy infrastructure. These threats are primarily flooding and storm weather systems, including hurricanes. In June and July of 2013 alone, 70,000 separate energy outages occurred in Vermont.**

- **Energy demand will rise as temperatures in both summer and winter increase. The temperature rise in summer and the increased use of air conditioning will likely outweigh the reduction in energy demand for heating in the winter. In Vermont, forecasts to 2030 anticipate peak energy load increasing .7% annually due to an increased demand for air conditioning.**

1. Overview of VT Comprehensive Energy Plan

In 2011, Governor Shumlin requested an updated version of a 1998 Comprehensive Energy Plan for the State of Vermont. This extensive document assesses past trends and projections for energy use in the state. Most importantly, it documents a plan for attaining the goal of 90% renewable energy use in Vermont by the year 2050. During the planning process, the Department of Public Service collected over 9,000 separate comments from citizens in Vermont related to the business sector, communities, town energy plans and policy recommendations.

The Comprehensive Energy Plan articulates the strategy for major reductions in Vermont's use of fossil fuels (Figure 4.1). The state hopes to essentially eliminate the use of oil by midcentury. Efforts to achieve this goal will focus in several areas. Increased energy efficiency is critical, along with the development and use of renewable sources of electricity, heating and transportation. Electric vehicle adoption will address energy for transportation, and natural gas and biofuels will remain a practical necessity as Vermont transitions away from oil.

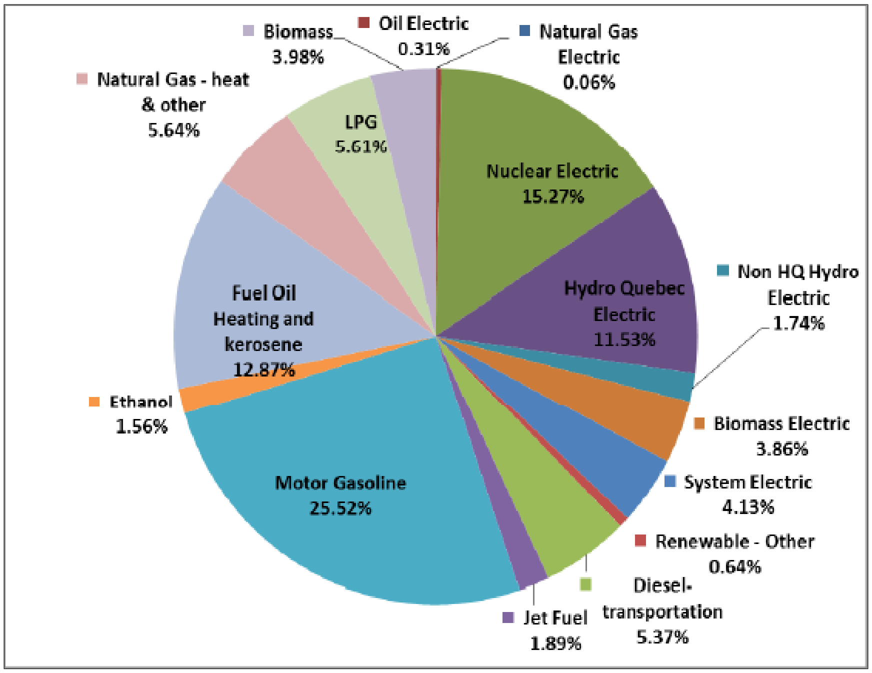


Figure 4.1 *Total energy use in Vermont, divided by fuel type. Source: Vermont Comprehensive Energy Plan, 2011.*

Four areas will provide focus towards pursuing 90% renewable energy by 2050: a) Outreach and Education, b) Finance and Funding, c) Innovation and Expertise and d) Regulatory Policy and Structures.

The Vermont Climate Assessment will contribute most directly to the area of Regulatory Policy and Structures with an overview of research related to energy efficiency behaviors that could inform effective policy.

2. Energy Policy in VT

Vermont has been very active in the development of energy policy promoting energy efficiency and renewable energy development. Areas of focus are overviewed below. For a more comprehensive discussion of public policy in Vermont, see Chapter 2.

2.1 Efficiency

Vermont is a national leader in policy creation designed to increase energy efficiency in residential and commercial settings. It was the first state to create a statewide "energy efficiency utility" in 1999 after the Vermont Legislature passed a law enabling the creation of Efficiency Vermont. "Efficiency Vermont provides technical assistance, rebates, and other financial incentives to help Vermont households and businesses reduce their energy costs with energy-efficient equipment, lighting, and approaches to construction and major renovation" (Efficiency Vermont website 2013).

In addition, Efficiency Vermont partners with other organizations around the state to provide options for increased efficiency and discounted services to customers related to thermal and electric efficiency. Efficiency Vermont is operated by the Vermont Energy Investment Corporation, under appointment by the Vermont Public Service Department.

2.2 Thermal

In 2012, the Vermont Public Service Department convened a Task Force, as recommended in the 2011 Comprehensive Energy Plan, to develop a detailed plan for a statewide whole-building approach to thermal efficiency.

2.3 Electric

In 2000, Vermont enacted Energy Efficiency Resource Standards, a policy approach affecting all sales of electricity in the state. Enacting this policy is expected to generate a savings of ~6.6% from 2012 to 2014. (http://aceee.org/files/pdf/policy-brief/eers-07-2013.pdf)

3. Impacts of Climate Change on Energy Supply and Production

Little doubt exists regarding whether or not the energy sector will be affected by climate change. The specifics and the time frame are unclear - but, energy supply and distribution in the United States will be affected by changes in storm frequency and intensity, temperatures, coastal flooding, in-land flooding and drought.

Three major climate trends are identified in a recent report developed by the U.S. Department of Energy (U.S. Department of Energy, 2013):

1. Increasing air and water temperatures
2. Decreasing water availability in some regions and seasons
3. Increasing intensity and frequency of storm events, flooding, and sea level rise

Of these three major trends, implications for New England and specifically Vermont include:

- **Transmission affected by increased temperatures**, which have the potential to decrease the efficiency of distribution when ambient temperatures are high
- **Renewable energy production** affected by **changing precipitation patterns,** particularly hydropower production and solar energy – wind generation might also be affected by changing wind patterns
- Threats to **energy supplies and infrastructure** from **storms and flooding** related to the refining and production of petroleum for heating and transportation and natural gas for electricity

- **Transmission** of electricity affected by direct **damage from increasing severity and frequency of storms,** and **flooding**

Energy sector	Climate projection	Potential implication
Oil and gas exploration and production	▪ Thawing permafrost in Arctic Alaska	▪ Damaged infrastructure and changes to existing operations
	▪ Longer sea ice-free season in Arctic Alaska	▪ Limited use of ice-based infrastructure; longer drilling season; new shipping routes
	▪ Decreasing water availability	▪ Impacts on drilling, production, and refining
	▪ Increasing intensity of storm events, sea level rise, and storm surge	▪ Increased risk of physical damage and disruption to offshore and coastal facilities
Fuel transport	▪ Reduction in river levels	▪ Disruption of barge transport of crude oil, petroleum products, and coal
	▪ Increasing intensity and frequency of flooding	▪ Disruption of rail and barge transport of crude oil, petroleum products, and coal
Thermoelectric power generation (Coal, natural gas, nuclear, geothermal and solar CSP)	▪ Increasing air temperatures	▪ Reduction in plant efficiencies and available generation capacity
	▪ Increasing water temperatures	▪ Reduction in plant efficiencies and available generation capacity; increased risk of exceeding thermal discharge limits
	▪ Decreasing water availability	▪ Reduction in available generation capacity; impacts on coal, natural gas, and nuclear fuel supply chains
	▪ Increasing intensity of storm events, sea level rise, and storm surge	▪ Increased risk of physical damage and disruption to coastal facilities
	▪ Increasing intensity and frequency of flooding	▪ Increased risk of physical damage and disruption to inland facilities
Hydropower	▪ Increasing temperatures and evaporative losses	▪ Reduction in available generation capacity and changes in operations
	▪ Changes in precipitation and decreasing snowpack	▪ Reduction in available generation capacity and changes in operations
	▪ Increasing intensity and frequency of flooding	▪ Increased risk of physical damage and changes in operations
Bioenergy and biofuel production	▪ Increasing air temperatures	▪ Increased irrigation demand and risk of crop damage from extreme heat events
	▪ Extended growing season	▪ Increased production
	▪ Decreasing water availability	▪ Decreased production
	▪ Sea level rise and increasing intensity and frequency of flooding	▪ Increased risk of crop damage
Wind energy	▪ Variation in wind patterns	▪ Uncertain impact on resource potential
Solar energy	▪ Increasing air temperatures	▪ Reduction in potential generation capacity
	▪ Decreasing water availability	▪ Reduction in CSP potential generation capacity
Electric grid	▪ Increasing air temperatures	▪ Reduction in transmission efficiency and available transmission capacity
	▪ More frequent and severe wildfires	▪ Increased risk of physical damage and decreased transmission capacity
	▪ Increasing intensity of storm events	▪ Increased risk of physical damage
Energy demand	▪ Increasing air temperatures	▪ Increased electricity demand for cooling; decreased fuel oil and natural gas demand for heating
	▪ Increasing magnitude and frequency of extreme heat events	▪ Increased peak electricity demand

Figure 4.2 Vulnerabilities to climate change by energy sector. This information was collected by the U.S. Department of Energy in "U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather", June 2013.

3.1 Energy Transmission

Increases in air temperature are projected to have an impact on the efficiency of energy transmission, particularly related to thermoelectric power plants. In Vermont this includes nuclear power plants, natural gas and biomass. A key process in energy generation involves a phase change of steam to a liquid after steam is heated, to drive a turbine to create electricity. Significant changes in air temperature will change the differential between the temperature of steam and the surrounding air, affecting the efficiency of energy generation. The expected changes in efficiency of these systems is small. However, over the long term and considered across the New England region, where Vermont shares power generation, significant impacts are possible. (U.S. Dept. of Energy, 2013).

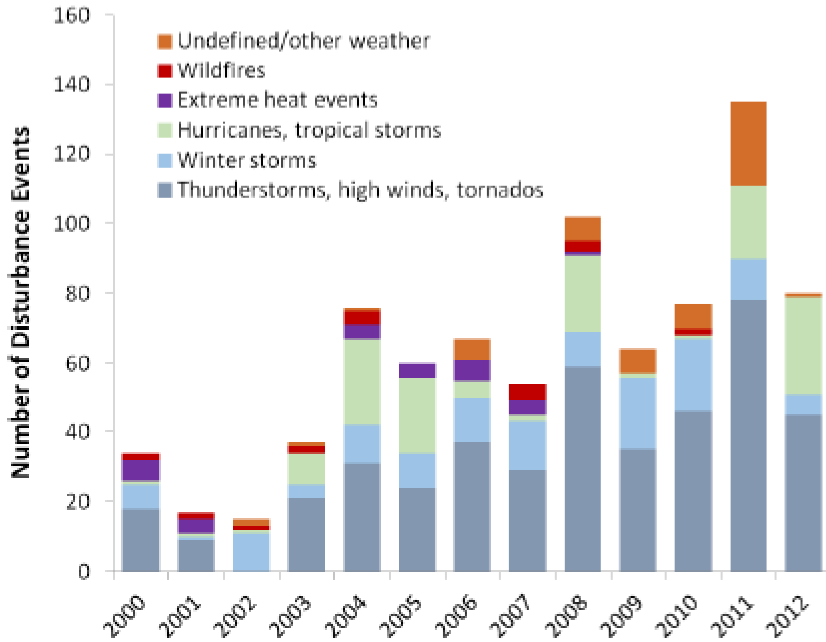


Figure 4.3 *Weather-related power disruptions across the United States are increasing. This graph depicts outages connected to weather events, from 2000 – 2012. Source: U.S. DOE "Energy Sector Vulnerabilities Report"*

During TS Irene 50,000 residents lost power – some for an extended period. Sustained winds of 50 mph impacted transmission lines, along with severe flooding that put many lines under water. Roads and bridges were decimated, making recovery efforts and energy systems repairs nearly impossible. Increasing severity of lightning storms could directly impact transmissions lines and transformers and outages caused by wind damage could also increase. *Storm impacts are covered further in Section 4.*

3.2 Impacts on Renewable Energy

Projections for **wind power** include changes in wind speed and wind patterns**.** However, these projections are inconsistent and vary according to the emissions scenario and climate model. Ultimately, there is no consensus in determining how wind power will be affected by changes in climate. Recent studies show that changes over the near term will not greatly exceed average historical variations (Pryor and Barthelmie 2011). However, it *is* possible that wind speeds could decrease in the Northeast, affecting wind power production. One study found that average annual wind speeds could decrease by 3-14% by mid-century (Sailor et al. 2008).

Solar energy production in Vermont could also be affected by increases in air temperature and increases in cloud cover. However, like wind energy production, this is an area for further study. Increasing temperatures do seem to affect photovoltaic output by decreasing efficiency, but the details of the change in power output depend on the materials used in the manufacturing of the panel. Further, though cloud cover and increased dust and haze could change the amount of solar radiation reaching the earth, the types of clouds (e.g. thin, cirrus clouds versus cumulous clouds) will determine the amount of blocked radiation. (Omubo-Pepple et al. 2009).

Hydropower plants, which comprise close to 50% of Vermont's electricity supply, could be affected by increasing temperatures. Increasing temperatures will likely increase evaporative water losses and impact watersheds, reducing available water and decreasing the amount of water available for hydropower. This could reduce peak generation capacity of hydropower stations over the long term (U.S. Dept. of Energy, 2013). Water quality could also be affected by changes in dissolved oxygen, influenced by increasing air and water temperatures, which could lead to eventual changes in biodiversity and ecological communities within watersheds.

A longer growing season in Vermont could be beneficial for **biofuels production**. The details of effects on plant growth will vary by region, soil type and growing conditions. It's possible that warmer temperatures could also increase evapotranspiration and demand for water. However increasing atmospheric CO_2 may increase water use efficiency in some species. Grower's responses to climatic changes will be key in managing climatic changes connected to biofuels.

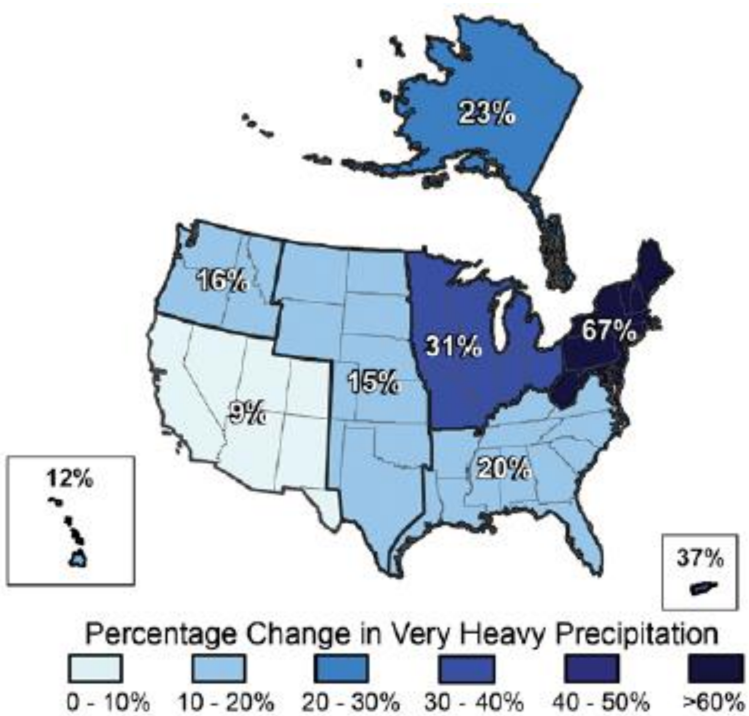


Figure 4.4 *Increases in heavy precipitation from 1958 – 2007. The Northeast will likely continue to see increases in heavy precipitation events. Source: U.S. DOE "Energy Sector Vulnerabilities Report"*

3.3 Inland and Coastal Flooding

It's likely that flooding is the most direct threat to Vermont's energy supply and distribution systems. Rainstorms are projected to become more intense, increasing the amount of precipitation falling during a single event (NOAA 2013). The figure below shows increases in precipitation by region from 1958 – 2007. The Northeast has experienced the greatest regional increases of any place in the United States. This trend is likely to continue (Betts, 2013).

4. Potential Effects of Major Storm Events on Energy Infrastructure and Supply

The potential for major disruptions from extreme weather events is an area of vulnerability for the energy supply in the Northeast, highlighted in several recent studies including two separate reports from the U.S. Department of Energy in 2013. The effect of climate change on hurricane strength and frequency is not fully understood by the scientific community. However, most models predict increased power in Atlantic hurricanes by the end of the 21st century, by 2-11% (NOAA, 2013).

Figure 4.5 *compares the effects of Hurricane Irene and Hurricane Sandy on energy supply and transmission. From the report, "Comparing the Impacts of Northeast Hurricanes on Energy Infrastructure."*

Impact	Irene	Sandy
Electric Customer Outages (millions)	6.69	8.66
Petroleum Refining Capacity Shut (barrels per day)	238,000	308,000
Petroleum Product Terminals Shut (number)	25	57

Source: OE/ISER Situation Reports

A new phenomenon recently observed by meteorologists and climatologists is the development and impacts of "quasi-stationary" weather systems. As moisture increases in the atmosphere, the Jet Stream seems to be slowing down. This causes "blocking" of major weather systems, limiting movement (Francis and Vavrus, 2012). Some scientists speculate that this phenomenon contributed to the effects of Hurricane Sandy and more recently, the 1,000-year flooding event in Colorado in September (Betts, 2011). This phenomenon undoubtedly needs more study. In addition, increases in lightning strikes during storms have been observed in Vermont. These weather affects, influenced by a changing climate, create serious challenges for energy supply and transmission.

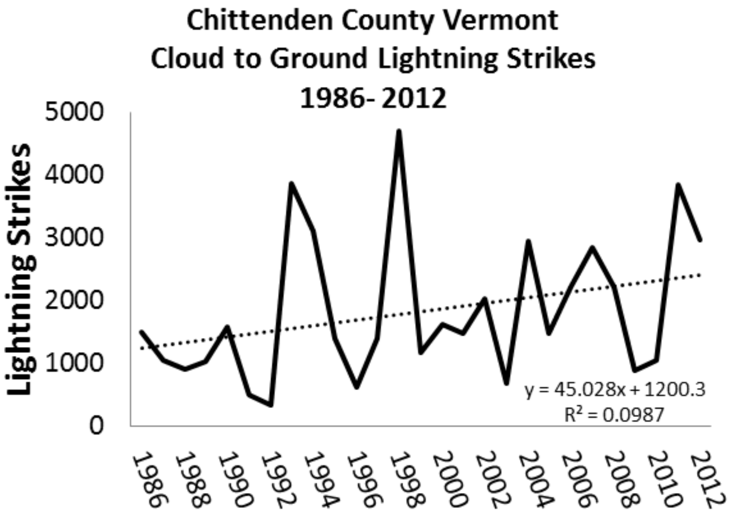
4.1 Atlantic Hurricanes

Hurricanes Katrina and Rita, occurring in the Gulf of Mexico and far from New England, both affected natural gas, oil and electricity markets in Vermont. Though Hurricane Sandy made landfall in New Jersey, its affects were experienced across the Northeast. Hurricane Irene caused power outages for 6.69 million people and affected petroleum processing capacity of up to 238,000 barrels a day. Hurricane Sandy had an even greater effect on power distribution across New England, though not in Vermont. Hurricanes Sandy and Irene are among the costliest and deadliest storms in U.S. history, according to the National Oceanic Atmospheric Administration (NOAA, 2013). There is reason to believe that hurricanes of this magnitude will impact the Northeast and Vermont in the future.

4.2 Increased Lightning Strikes

With an expected increase in frequency and intensity of major storm events, increased lighting activity is also highly probable. A subtle upward trend of lightning strikes has been observed in Vermont since 1986 (Chapter 1, Figure 4.6). Lightning is a well-known cause of power outages,

Figure 4.5. *Chittenden County, Vermont: Cloud to ground lightning strikes (Chapter 1, this report).*



Includes +/- Strikes

both due to direct strikes and indirect effects, often occurring when a tree limb falls on a power line.

The potential for disruption to the current energy supply associated with weather events is recognized in the Comprehensive Energy Plan and a major report entitled, "Energy Assurance Plan" was completed in August 2013 by the Vermont Department of Public Service. This report covers the details of a state-level response to a major disruption in energy. This includes preparedness drills and a clear set of directives in the case of major events. The report also acknowledges the vulnerability of the state's systems. For instance, natural gas heats approximately 15% of Vermont's homes. None of this supply comes from within the state. The delivery of natural gas "depends on the [vulnerabilities of the] state transportation system, primarily flooding and wash-outs and snow and ice" (Energy Assurance Plan, 2013). The same vulnerabilities exist for oil supplies, which heat 50% of homes in Vermont. In the report, Tropical Storm Irene is acknowledged as a difficult and valuable learning experience that exposed weakness in energy preparedness. The Energy Assurance Plan attempts to address those weaknesses and create systems that are well structured and resilient to major disruption.

5. Increased Energy Use due to Warming Temperatures

As winter temperatures increase, Vermont will use less fuel for heating and compared to other regions in the country and will see the second largest decrease in natural gas use for thermal energy production. However, summer temperatures will also increase and consumers will use more electricity for air conditioning. Thus, the net energy change in Vermont will increase over the coming decades. VELCO, the state's energy transmission company, projects an increase in electric energy use of .4% annually to 2030. A peak load increase in the summer, due to air conditioning is expected to be .7% annually to 2030 (Comprehensive Energy Plan, 2011).

The image below displays an estimate of changes in "cooling degree days" and "heating degree days". A cooling degree day is a day with an average temperature over 65 degrees, theoretically requiring air conditioning in buildings. A heating degree day is a day of temperatures under 65 degrees, when a heating system might be turned on in a building. Vermont will see an increase by 10, in cooling degree days from 2041-2070, explained in the chart below. Compared to national averages, Vermont will not see the extreme temperature swings that will likely occur in other areas of the nation.

Region	Consequences: Challenges and Opportunities — Electricity Use	Consequences: Challenges and Opportunities — Natural Gas (Heating)
Physical Impacts - High Likelihood	**Warmer and longer summers** Number of Additional Extreme Days(> 95°F) and % Increase in Cooling Degree Days in 2041-2070 above 1971-2000 Level	**Warmer winters** Number of Fewer Extreme (< 10°F) Cold Days and % Decrease in Heating Degree Days in 2041-2070 below 1971-2000 Level
Northeast	+ 10 days, +77%	- 12 days, - 17%
Southeast	+23 days, 43%	- 2 days, - 19%
Midwest	+ 33 days, +64%	- 14 days, - 15%
Great Plains	+ 22 days, +37%	- 4 days, -18%
Southwest	+ 20 days, +44%	- 3 days, - 20%
Northwest	+ 5 days, +89%	- 7 days, - 15%
Alaska	Assumed Neutral - Not modeled	Assumed - Not modeled
Pacific Islands	Assumed - Not modeled	Assumed Neutral – Not modeled

Figure 4.6. *Cooling degree days and heating degree days estimated for the Northeast are compared here to other regions of the country. According to this comparison, Vermont's overall energy use will increase but not dramatically, compared to other places. This is good news for Vermonters. (Melillo et al. 2014).*

6. Mitigation – Energy Efficiency and Conservation

6.1 Electric

The CEP clearly outlines the importance of increased efficiency and conservation efforts in meeting state energy use reduction goals. The creation of Efficiency Vermont in 2009, along with other efficiency programs, has contributed significantly to increased energy efficiency and since 2004, the state has reduced electric demand by an average of 2% annually. Overall energy demand increases have been near 0% for the past ten years. Vermont currently leads the nation in electric efficiency investments and calculations show that a year of investments in efficiency currently yields $5 to the state for every $1 spent. Nonetheless, efforts to improve insulation in homes, landed Vermont far behind the state's goal of insulating 8,200 home per year by 2020. Though 6,700 homes have been insulated since 2008, the pace must increase to meet the challenge of insulating the state's goal of a total of 80,000 homes by 2020 (Comprehensive Energy Plan, 2011).

6.2 Transportation

Transportation is another area for increased energy conservation and efficiency. Due to the rural nature of the state, Vermonters drive most places and combustion of fossil fuels for transportation accounts for almost half of the state's overall energy use. Increasing the purchase and use of electric vehicles has been identified as a key strategy in reducing greenhouse gas emissions associated with transportation. Along these lines, opportunities for strategic land use planning and personal decisions about where to buy a home could have an impact on driving behavior. Overall, if Vermont is to meet the goals of 90% renewable energy by 2050, conservation and efficiency efforts must increase.

7. Behavior Change and Energy Use

The field of Behavioral Science has increasingly attracted interest from energy and policy experts. Insights from behavioral studies offer tools to understand and incentivize behaviors related to energy efficiency and use. Critically, these insights can be applied in the area of policy and highlight leverage points for policy makers. Areas of research related to behavior change originate in the fields of marketing and consumer research, but more recently have been applied in the areas of health, education and energy. Britain's "Nudge Unit" applies research from behavioral economics to address a plethora of policy challenges and is rapidly becoming a model

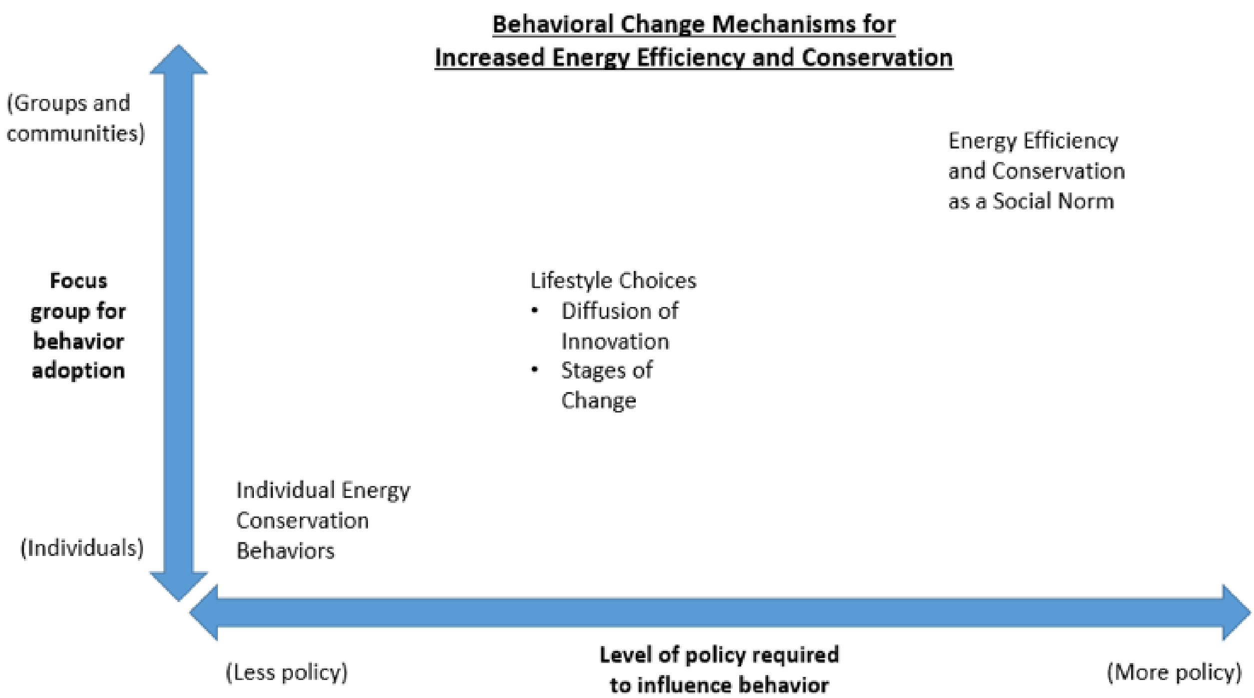


Figure 4.7. *The graphic displays an outline of how policies might interface with behavioral change mechanisms. Certain mechanisms will be more difficult to adopt than others – but, it's possible that changes with the most cumulative impact are relatively easy to implement.*

for other policy institutions, including the U.S. Government (Bennhold, 2013). Several main streams of research and the implications for policy are covered below.

7.1 Informational Feedback

A substantive body of research exists from the last four decades on the effect of informational feedback on consumer behavior. A review of various programs implementing the use of direct information feedback consistently finds energy savings ranging up to 20% for consumers monitoring their energy use. For example, In-Home Displays (IHDs) show consumers' their real-time energy use and show an average reduction of energy use around 10% (Darby, 2006). These instruments have shown to be powerful tools for increasing consumers' awareness of actions that contribute to energy use and conservation behaviors. In some instances, monitoring home energy use also caused a "spillover" effect into other decisions – like how much to drive or fly (Hargreaves, 2010). When pay-as-you-go systems for electricity consumption were included as part of the program, consumers were able to reduce energy consumption by an average of 15-20% (Darby 2006). The research is clear that informational feedback for customers leads to behavior changes that can reduce energy consumption.

7.2 Policy Connections to Informational Feedback

The arrival of the Smart grid in Vermont will undoubtedly lead to more information for energy customers. However, the research shows that real-time energy information is the key to behavior change that equals energy conservation. According to Green Mountain Power's website, smart meter information on energy usage will be easily available on an internet webpage. In addition, smartphone apps are under development. Though the information accessible on a webpage will vastly increase the amount of information available to consumers, In-Home Displays, showing real time data, have been tested and demonstrated to reduce energy consumption. Combining the information available from smart meter technology with In-Home Displays would undoubtedly show significant results in energy reduction. A pilot study conducted in Texas, with Center Point Energy utility found that 71% of participants using IHDs displaying smart meter information on their energy use, engaged in action to reduce their energy consumption (Center Point Energy, 2011).

Vermont could introduce legislation offering rebates for the purchase of IHDs or pass similar policies ensuring that energy use information is available to consumers on a consistent basis, in a useable manner.

Box 4.1 NUDGING ENERGY EFFICIENCY

Three years ago, Britain's Prime Minister, David Cameron, picked up the book, *Nudge.* This small book inspired a revolution in how Britain is addressing complex public policy problems; from unemployment and smoking, to paying taxes and insulating attics.

Britain's Behavioral Insights Team develops ideas and strategies designed to "nudge" citizens' decisions in the direction of pro-social behavior. By developing ideas and then testing them, the team has uncovered effective mechanisms for changing behavior in Britain.

A recent achievement is the success of a program designed to increase residential attic insulations. After including a "loft clearing" service with the insulation process, participation in the program rose dramatically. The Behavioral Insights Team identified the hidden deterrent to attic insulation – residents didn't want to clear their attics! This insight ultimately led to dramatic energy savings. There's something we can learn here from the Brits.

7.3 Energy Conservation as a Societal "Norm"

The creation of "social norms" associated with environmental conservation and specifically energy conservation, is another well-studied arena. There is good evidence that consumers are influenced by similar members in a group, often very strongly. Particularly when individuals have similar personal characteristics with another person, they are likely to be influenced by that person's behaviors. A study of guests in hotel rooms found that people were more likely to engage in an "environmental" behavior when they learned that the guest who stayed in their hotel room previously engaged in that behavior – in this case, choosing to reuse towels instead of having them washed (Goldstein, 2008). Similarly, an extensive study of the energy conservation program, OPOWER, finds that consumers are consistently influenced by peers' energy use. An average energy reduction of 2% was found by sending letters to consumers with information about their neighbors' energy use (Allcot, 2010). This energy reduction is roughly equal to a 5 – 11% price increase.

7.4 Policy Connections to Energy Conservation as a Societal Norm

Currently, neither Green Mountain Power (GMP) nor Burlington Electric use the OPOWER program and do not compare other customers' energy use on energy bills. A conversation with a representative from GMP confirmed that the utility is aware of the program and has discussed implementation (Dorothy Schure, personal communication, Nov. 4, 2013). However, at the time of this writing, GMP has prioritized the smooth transition of Central Vermont Public Service Corporation's software systems, following the merger of the two companies.

Encouraging the use of this relatively simple and cost effective tool for energy consumers is low-hanging fruit for policy makers. Extensive research has been conducted on the efficacy of the OPOWER program and makes a strong case for non-price interventions that can affect consumer behavior. The use of social norms could also be extended to other areas of energy use.

Box 4.2 Driving Demand: A Case Study

Figure 4.8. *The Hood River Conservation Project logo was influenced by the orchards in River, a point of regional pride*

A major report titled, “Driving Demand for Home Energy Improvements” published in 2010 and funded by the Department of Energy, investigates behavioral change related to energy use in fourteen different case studies of utilities across the country. The focus in the case studies was understanding consumer decisions to upgrade homes for increased energy efficiency. The focus on the consumer – not economics or technology – is new in understanding energy efficiency and energy use in general, and can be informative for other behaviors.

The various projects associated with the report applied theories of behavioral change to program design and implementation. For instance, in Hood River, Oregon, a highly successful project to increase home energy efficiency (85% implementation of energy upgrades), used social network theory to design a marketing plan that analyzed the social connections within the Hood River community.

In analyzing the program, the program leaders discovered that the contractors installing the updates became initial ambassadors and had significant influence on how consumers viewed the products. If a problem existed with the initial installation of an upgrade, a contractor’s mistake could influence perception and acceptance of the entire program. Other insights were gained from a year-long process of studying local attitudes towards issues connected to energy. For instance, Hood River residents dislike orders from outsiders, are concerned about fairness and are suspicious of things that are free.

These insights helped program directors design and implement a plan that was responsive to customers’ concerns and capitalized on the unique attributes of the Hood River Community.
The entire project, comprising fourteen programs, found themes connected to the adoption of new behaviors that increased energy efficiency in homes. A few of these themes are listed below.

- **Programs must sell something that people want** – most people are not emotionally connected to the idea of reducing energy use; people feel more connected to ideas of health, security and safety. Reducing energy use or purchasing an electric car must be connected to values that resonate with customers.
- **Target the population and spend the necessary time and money to understand that population**. Not all consumers are the same – understanding the values and characteristics of the target populations will greatly increase the likelihood of developing a campaign that resonates.
- **Framing is important**. In these studies, words like “audit” and “retrofit” did little to help people understand the issues and framed things negatively. Words that tap into existing mental models are more useful. Framing in terms of community can help customers see the broader value of reducing energy use or supporting renewable energy.
- **Most consumers need to hear a message at least three times before adoption**. An effective marketing campaign will include various methods for connecting to potential customers.

Although this study focuses on energy efficiency upgrades, many of the lessons learned can be extended to other energy issues like electric car campaigns and the adoption of renewable energy technology. To access the report go to: http://drivingdemand.lbl.gov/

7.5 Diffusion of Innovation

The research on the diffusion of innovations developed in the field of marketing and consumer behavior. According to this theory, the way in which trends or innovations "take-off" in a society (or don't) depends upon several key factors. Most important, is the ability of an innovation to "be reinvented" through modifications by users. A key question is: How well does the innovation evolve to meet the needs of more people? Everett Rogers, the preeminent scholar in this field divides people into five categories that determine how quickly they pick up a new idea or technology and thus, whether or not it will survive. The five different segments of the population are; **innovators** – who pick up ideas quickly, **early adopters** – who are often financially secure and comfortable with risk, **early and late majority** – this represents most people in society and they are cost- sensitive and risk-averse, and **laggards** – they see high risk in adopting a new idea and are usually last on board, if at all. Understanding these five groups allows a marketer or firm to focus their efforts. This last point is critical. In moving the population towards increased energy efficiency and conservation, the efforts must be focused and strategic (Rogers, 1962). Depending upon the stage of "diffusion" for a specific idea or technology, a marketer's approach will vary. For instance in the early stages of adoption, media and advertising play an important role, while in the later stages of an adoption, conversations with peers are very important.

In a study exploring consumer motivations for the purchase of hybrid vehicles, experimenters used 'diffusion of innovation' theory (along with several other behavioral theories) to understand why people buy hybrid vehicles and how to encourage this behavior. In general, the study showed that the adoption of "green" technologies is a social process (Ozaki et. al, 2009). This process can be described in five stages. Everett Rogers identifies these stages as: acquiring information about the technology through social networks, forming and attitude towards it; deciding to adopt the technology or not implementing it and confirming or maintaining the decision. The second stage, "forming an attitude" is of specific importance. This is when an innovation will either be embraced or discarded by consumers – and this all depends on how the innovation is viewed. In the case of hybrid vehicle purchase, consumers identified financial benefits and environmental benefits as central to their decision to buy a hybrid, and "adopt" the innovation. Upon investigation, the authors of the study found that the importance of financial benefits trumped environmental benefits (though environmental benefits *were* important and related to social norms and a desire to be perceived as environmental). The decision to purchase (or adopt) a new innovation like hybrid vehicles or electric cars is multi-faceted and complex. Understanding the social processes of adopting new energy efficiency and conservation technologies is critical to their ultimate success.

7.6 Policy Connections to Diffusion of Innovation

In the study mentioned above, financial incentives were the most important factor in consumers' decisions to purchase hybrid vehicles in the United Kingdom. The financial benefits highlighted most by survey respondents related to lower gasoline costs, lower road taxes, accessibility to town centers and priority or free parking. This shows that policy makers have an important role to play in the adoption of new technologies. Hybrid vehicles were determined to be highly beneficial to consumers who purchased them, due in large part to financial benefits created by policy mechanisms. The study also shows that the perception of an innovation as "environmental" can have a large impact on its adoption, particularly when there's social pressure to make environmental decisions. Thus, it's important for industry and government to help to craft the discourse around the adoption of new, energy efficient technologies, like electric cars in Vermont.

7.7 Stages of Change Model, Theory of Reasoned Action and the Theory of Planned Behavior

Stages of Change behavioral theory refers to individual choices and factors that move a consumer to adopt a new behavior. This model has been applied most often to behavior changes related to health, like diet changes or the cessation of smoking. Scholars identify four main stages in a fundamental behavior change:

1. Pre-change behavior (like contemplation of a change)
2. Preparation
3. Action
4. Post-change stages (like maintenance or relapse)

This relates closely to the Theory of Reasoned Action (TRA), which states that the most important element of a major behavior change is the intention. The Theory of Planned Behavior (TPB), focuses on consumers' beliefs and attitudes towards certain behaviors and the eventual adoption of behaviors. TPB asserts that intentions do not always translate to behavior.

7.8 Policy Connections to Stages of Change Model, Theory of Reasoned Action and the Theory of Planned Behavior

A recent study on the process of quitting smoking, might lend itself to understanding how major behaviors take shape and where policy might intervene in promoting energy efficiency and conservation (Deir et. al 2011). An examination of study participants in various stages of smoking addiction (smokers, trying to quit, never smokers), found that the most success from interventions was in educating and supporting the "never smokers". Individuals at various other stages of change had higher relapse percentages than those already at the "maintenance" stage of smoking. That is, the "never smokers" had reached "success" defined by the maintenance stage. By educating this population, it is possible to influence their continued behaviors and may garner the most benefits to individual and societal health for the least amount of resources. Connections to energy policy emphasize again, the importance of targeting an audience with educational efforts and messaging. Stages of Change, the Theory of Planned Behaviors and Theory of Reasoned Action help to identify different stages towards adopting an action and offer insight into the complexity of behavior. These theories also emphasize the importance of education for young consumers who will grow to be influential decision makers and will also create social norms. Energy education in schools should be a part of public policy efforts.

8. Summary Table Rating Quality of Information

Key Message 1	**Energy efficiency and conservation are key components of Vermont's goal of 90% renewable energy sources by 2050. Understanding mechanisms that can increase energy efficiency and conservation behaviors are central to this challenge. Policy decisions that leverage an understanding of behavior change could profoundly support this mitigation effort.**
Description of evidence base	Goldstein, N., Cialdini, R., Griskevicius, V., (2008). A Room with a Viewpoint: Using Social Norms to Motivate Environmental Conservation in Hotels. Journal of Consumer Research, Vo. 35, No. 3, 472-482. Allcott, H., (2010). Social Norms and Energy Conservation. Journal of Public Economics, 95, 1082-1095. Ozaki, R., Sevastyanova, K., (2010). Going hybrid: An analysis of consumer purchase motivations. Energy Policy, 39, 2217-2227. Center Point Energy (2011, July). In-Home Displays Pilot. Retrieved from: www.centerpoint.com Bennhold, K., (2013, December 7). Britain's Ministry of Nudges. NYTimes. Retrieved from: http://www.nytimes.com/2013/12/08/business/international/britains-ministry-of-nudges
Assessment of confidence based on evidence	Given the evidence base and remaining uncertainties, confidence is **very high** that enacting behavioral change could improve energy conservation in the state of Vermont
CONFIDENCE LEVEL	

Very High	**High**	**Medium**	**Low**

Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Key Message 2	**Adaptation through the use of renewable, local energy sources will be increasingly important as extreme weather events increase and threaten fossil fuel energy supplies. In addition, reducing reliance on international energy supplies increases Vermont's energy security. Current policies in Vermont create opportunities for local, renewable energy development.**
Description of evidence base	U.S. Department of Energy. (June 2013). U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather. Retrieved from http://energy.gov/sites/prod/files/2013/07/f2/20130716-Energy%20Sector Betts, A. K. (2011). Climate Change in Vermont. Atmospheric Research Report, prepared for Agency of Natural Resources, State of Vermont. Retrieved from http://www.uvm.edu/~epscor/pdfFiles/2013_workshop/VTCCAdaptClimateChangeVTBetts.pdf Vermont Department of Public Service (August 2013). State of Vermont Energy Assurance Plan. (Project No. DE-OE0000107).
Assessment of confidence based on evidence	Given the evidence base and remaining uncertainties, confidence is **high** that enacting local energy sources could make Vermont more resilient to climate shocks.

CONFIDENCE LEVEL

Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well	Moderate evidence (several sources, some consistency, methods vary and/or	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging,	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation

documented and accepted methods, etc.), high consensus	documentation limited, etc.), medium consensus	etc.), competing schools of thought	and/or methods not tested, etc.), disagreement or lack of opinions among experts

Key Message 3	Increased risk of major storm events in Vermont will threaten energy infrastructure. These threats are primarily flooding and storm weather systems, including hurricanes and electrical storms. In June and July of 2013 alone, 70,000 separate energy outages occurred in Vermont.
Description of evidence base	Chapter 1, this report. U.S. Department of Energy. (June 2013). U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather. Retrieved from http://energy.gov/sites/prod/files/2013/07/f2/20130716-Energy%20Sector U.S. Department of Energy. (April 2013). Comparing the Impacts of Northeast Hurricanes on Energy Infrastructure. http://www.oe.netl.doe.gov/docs/Northeast%20Storm%20Comparison_FINAL_041513c.pdf
Assessment of confidence based on evidence	Given the evidence base and remaining uncertainties, confidence is **high** that major storm events will threaten Vermont's energy infrastructure.

CONFIDENCE LEVEL

Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Key Message 3	Energy demand will rise as temperatures in both summer and winter increase. The temperature rise in summer and the increased use of air conditioning will likely outweigh the reduction in energy demand for heating in the winter. In Vermont, forecasts to 2030 anticipate peak energy load increasing .7% annually due to an increased demand for air conditioning.
Description of evidence base	Chapter 1, this report. Melillo et al., 2014 Vermont Public Service Department. (2011). Comprehensive Energy Plan. Retrieved from: http://publicservice.vermont.gov/publications/energy_plan
Assessment of confidence based on evidence	Given the evidence base and remaining uncertainties, confidence is **high** that major storm events will threaten Vermont's energy infrastructure.

CONFIDENCE LEVEL

Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Chapter 5: Water Resources

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Key Messages

- **As average annual rainfall has increased in recent decades, average annual flows in Vermont rivers have increased. Based on climate model projections for increased precipitation, average annual streamflows can be expected to continue increasing in coming decades.**
- **Warming temperatures are leading to earlier thaw dates on Vermont rivers, lakes and ponds as well as earlier thaw dates for snowpack in the mountains. Earlier thaw dates and changing precipitation patterns have caused streamflows to shift seasonally. Average monthly flows in January and March, as well as July, August, and October through December, have increased while average monthly flows in April and May have decreased.**
- **High flows are larger in magnitude and are occurring more frequently, often in the winter months associated with earlier thaw dates for snowpack. In the coming decades, climate models project that a greater fraction of winter precipitation will fall as rain or freezing rain rather than snow, leading to rain-on-snow events and rain on frozen ground, with associated flooding. Up to an 80% increase in the probability of high flows is projected under assumptions of high green-house-gas emissions by the end of the century.**
- **Warming temperatures and an expected increase in seasonal variability of rainfall and runoff may increase the potential for summer dry spells by century's end. Evidence suggests that Vermont rivers have sustained higher base flows during summer months over recent decades, in contrast to other parts of New England (coastal Maine) and the US. However, climate projections indicate an increased potential for dry spells in summer months by the end of the century, which could lead to extended periods of very low stream and lake levels and reduced recharge to groundwater.**
- **Changing rainfall, runoff and temperature patterns will affect availability and reliability of water resources to a variety of Vermont sectors (e.g., agriculture, communities, tourism, energy) in complex ways.**

1. Water Resources of Vermont

Water resources of Vermont comprise both surface water and groundwater. Vermont surface waters include approximately 24,500 miles of rivers and streams[3]; 824 lakes, reservoirs and ponds; and more than 290,000 acres of wetlands[4]. Surface waters of the state drain to one of four major basins: Lake Champlain to the north and west, Lake Memphremagog to the northeast, the Hudson River to the southwest and the Connecticut River to the east and southeast. Surface waters are managed for multiple uses including: support to aquatic organisms and wildlife, drinking water, swimming, boating, fishing, snow-making, agriculture (irrigation and livestock), flood control, and industrial processes including cooling a nuclear power plant.

Groundwater is stored below the ground surface in soils, in spaces between sand and gravel particles, and in fractures or other partings of the bedrock. Nearly 70% percent of Vermont's population[5] depends on groundwater for their drinking water supply. Groundwater is also used for agriculture (livestock), commercial developments, mining, and manufacturing. Groundwater returns flow to lakes, ponds, and wetlands, and thereby sustains our multi-varied uses of surface water and supports aquatic habitats.

This Water Chapter of the Vermont Climate Assessment addresses how climate change will affect our water resources. Key messages are provided below, along with supporting evidence for observed historic trends and projected future trends. This chapter discusses likely or potential impacts to our natural and built systems as a result of water-related climate-change impacts. Also presented are opportunities to build greater resilience in the face of climate change.

2. Greater Runoff and Annual Streamflows

As average annual rainfall has increased in recent decades (see Chapter 1), average annual flows in Vermont rivers have increased. Based on climate model projections for increased precipitation, average annual streamflows can be expected to continue increasing in coming decades.

In any given rain event, the fraction of rain and snow-melt that runs off the land surface to rivers, streams, lakes and wetlands - versus that fraction that soaks into the soil and is available for use by vegetation and recharge to underlying stores of groundwater - is a complex function of topography, geology, land cover/use and pre-existing soil moisture conditions. Mountainous regions of Vermont receive greater amounts of rain and snow than the lowlands. Mean annual precipitation ranges from a low of 32 inches per year in the Champlain Valley, to 36 inches per year in the Connecticut River valley, to over 50 inches per year along the north-south trending spine of the Green Mountains (Randall, 1996). High relief in the mountains, as well as the predominance of low-permeability glacial till and shallow bedrock leads to more rapid runoff from rain and snowmelt. Headwater channels are steep and often confined closely by valley walls, and flows can be flashy in nature. In contrast, the lowlands are generally lower in gradient

[3] National Hydrography Dataset, 1:5000 scale

[4] VT 2012 Water Quality Integrated Assessment Report, http://www.vtwaterquality.org/mapp/docs/305b/mp_305b-2012.pdf

[5] Vermont population: 625,741 (2010 census)

and characterized by thicker deposits of sediments overlying bedrock. Floodplains are typically wider and there are more wetlands, lakes and ponds to provide for storage and attenuation of storm flows. Mean annual runoff ranges from more than 35 inches per year along the spine of the Green Mountains to less than 12 inches per year in the Champlain Valley (Randall, 1996). On a regional and local basis, land cover will influence the magnitude and intensity of runoff. For example, developed lands are typically characterized by pavement, roads, roof tops and other impervious surfaces that tend to block infiltration of rainwater and snowmelt, leading to more runoff. In contrast, naturally forested lands tend to be characterized by tree canopies, understory vegetation and well-developed soils that promote interception and re-evaporation by canopies, and greater infiltration of rainfall and snowmelt. Runoff from forested lands is generally much lower in volume and intensity than runoff from developed lands.

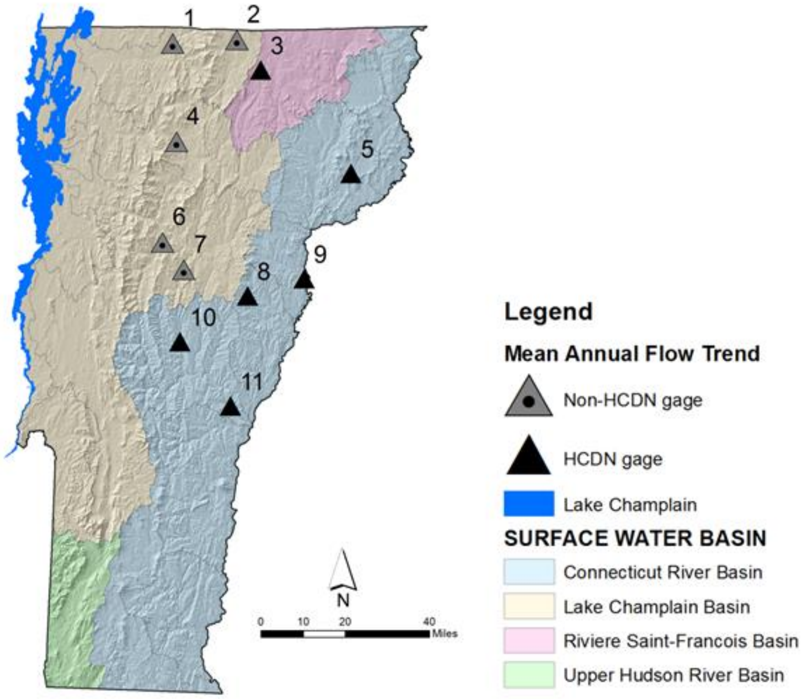
1.1 Historic trends

A network of river gages has been established across the nation by the United States Geological Survey (USGS) to continuously measure streamflow in select rivers. A subset of USGS streamflow gages has been selected to track impacts of climate change on river flows (Slack and Landwehr, 1992). Rivers in this Hydro-Climatic Data Network (HCDN) network were selected because they have available a relatively long streamflow gaging record, and because they drain watersheds that have been minimally impacted by impoundments, channel diversion or other changes in land use that might significantly influence streamflow over the period of record. Several of these rivers are located in New England, and have been evaluated for trends attributed to effects of climate change. Average annual flows in these New England rivers have increased over the past half century (Hodgkins & Dudley, 2005; Huntington *et al.*, 2009).

Similar increasing trends in average yearly flows are apparent for eleven Vermont rivers (Figure 5.1). While not all of these rivers are officially a part of the USGS Hydro-Climatic Data Network, they have been reviewed and determined to be minimally influenced by flow regulations (dams, diversions) or land use changes (Guilbert & Underwood, 2013; Hodgkins *et al.*, 2010). According to USGS State Water-Data Reports, there have been times, either historically or at present, when eight of the eleven gages have exhibited an infrequent or occasional diurnal (daily) signal during low-flow conditions as a result of a distant upstream mill dam(s) or power dam(s). However, these conditions do not constitute a significant flow regulation in the upstream watershed capable of affecting the use of these gages to evaluate long-term trends in streamflow (Hodgkins *et al.*, 2010; Hodgkins & Dudley, 2011).

1.2 Projected Trends

Under high-emission modeling scenarios, surface runoff is projected to increase by 3.6 inches per year by mid-century and by 6.5 in./yr. by end-of-century (Huntington *et al.,* 2007). With these expected increases in surface runoff, climate models project continued increases in average annual streamflow by the end of the 21st century.



No.	USGS Station	HCDN	Description	Years of Record	Trend	p-value
1	04293500		Missisquoi River Near East Berkshire, VT	92	+	**0.005**
2	04293000		Missisquoi River Near North Troy, VT	80	+	**0.017**
3	04296000	✓	Black River at Coventry, VT	61	+	**0.011**
4	04292000		Lamoille River at Johnson, VT	84	+	**0.001**
5	01134500	✓	Moose River at Victory, VT	65	+	**0.004**
6	04288000		Mad River Near Moretown, VT	84	+	**0.004**
7	04287000		Dog River at Northfield Falls, VT	77	+	**0.024**
8	01139800	✓	East Orange Branch at East Orange, VT	54	+	**0.031**
9	01139000	✓	Wells River at Wells River, VT	72	+	**0.010**
10	01142500	✓	Ayers Brook at Randolph, VT	73	+	**0.002**
11	01144000	✓	White River at West Hartford, VT	96	+	**0.014**

Figure 5.1. *Historic trends in mean annual flows for select Vermont rivers. Positive trend (upward arrow) indicates increased discharge. Trend is statistically significant ($p<0.05$; Mann-Kendall) for all eleven rivers.(Guilbert & Underwood, 2013, unpublished data; after Hodgkins et al., 2010)*

1.3 Impacts

Generally, greater amounts of rainfall will mean greater amounts of stormwater runoff to receiving channels. In developed areas, rainfall and snowmelt will quickly run off impervious surfaces to the nearest swale or stream. To the extent that stormwater runoff is not controlled or managed through treatments prescribed by state or local regulations, runoff diverted overland in this way will have higher velocities and therefore an increased capability to erode sediment and debris from the land surface. Concentrated runoff will lead to increased gullying, and erosion of sediments from the land surface, roads, ditches and streambanks.

In addition to sediment, there will be an increased potential for delivery of nutrients, pathogens and toxins to Vermont rivers and lakes. Collectively, these diffuse sources of pollution are termed nonpoint source pollution. Based on more than twenty years of monitoring river contributions to Lake Champlain, nonpoint source pollutants increase substantially as streamflow volumes rise (LCBP, 2012; Stager & Thill, 2010; Medalie & Sullivan *et al*., 2009; Smeltzer & Simoneau, 2008). Spring flooding during 2011 mobilized significant volumes of sediment and nutrients to Lake Champlain (LCBP, 2012).

Figure 5.2. *Blue-green algae bloom on Lake Champlain looking south from Missisquoi Bay Bridge. Photo credit: Lake Champlain Basin Program.*

In rivers, excess nutrients and sediments can lead to enhanced algae production and other changes in water quality (e.g., siltation) that reduce the channel's capacity to support macroinvertebrates, fish, freshwater mussels, and other aquatic organisms. In receiving lakes, excess nutrients and warmer water temperatures can lead to more frequent blooms of blue-green algae which represent a potential threat to human and animal health (Figure 5.2). These changes also have the potential to impact aesthetics and recreational uses of our waterways.

Greater amounts of annual precipitation will likely lead to increases in average annual lake levels. Stager & Thill (2010) note that "if annual precipitation increases 4–6 inches by the end of this century as most models suggest under [a high-GHG-emission] scenario, and if the relationship between precipitation and surface levels still follows its current pattern, then Lake Champlain could stand as much as 1-2 feet higher, on average, by 2100". The projected variability in precipitation (higher highs and lower lows) may lead to a "wider range of lake level fluctuations over the course of the year" (Stager & Thill, 2010). Rising lake levels may increase or decrease the shallow lake-edge habitats, depending upon the local topography and the presence of infrastructure (e.g., roads that may constrain lake levels).

On forest lands, accelerated runoff (increased flow peaks and magnitudes) as well as sediment loading can result if networks of logging access roads, skidder trails, and logging landings are poorly-managed where these features intersect with the stream network (Wemple *et al.*, 1996).

Where stormwater is not well managed on farms, increased runoff may result in increased mobilization of sediment, pathogens, and nutrients from concentrated feeding operations, barnyards, and manure or sileage storage areas. Streambank erosion can be accelerated in locations where naturally-vegetated riparian buffers have been removed to facilitate cultivation, livestock pasturing, or development.

Substantial volumes of sediment (often nutrient-laden) erode from ditches and enter surface waters where road and driveway networks intersect the stream network. These effects are particularly significant during intense rains or flood events (Figure 5.3).

Figure 5.3. Washout on North Road, Middletown Springs, VT during Tropical Storm Irene (28 August 2011). Photo credit: Hilary Solomon, Poultney-

Wastewater treatment facilities that are not completely disconnected from storm sewers may become overwhelmed by stormwater volumes, allowing for the possibility of increased contamination to receiving lakes or rivers (US EPA, 2008).

1.4 Opportunities to Build Resilience

Several mitigation and adaptation strategies are possible to address the likelihood for greater runoff and increased average annual streamflows in the coming century.

- Restore wetlands and protect river corridors to enhance the flow and sediment attenuation role of the riparian areas surrounding Vermont rivers, as well as mitigate for water quality impacts (Kline & Cahoon, 2010).

- Improve compliance with *Acceptable Management Practices (AMPs)*[6] *for Maintaining Water Quality on Logging Jobs in Vermont* on private and public lands. Forest management practices that maximize infiltration of rainfall and runoff will reduce peak flows from the headwaters and minimize runoff of sediment and nutrients to rivers, lakes and wetlands.

- Improve compliance with *Acceptable Agricultural Practices* (AAPs)[7] on agriculture lands. Manage nutrient applications so that phosphorus and nitrogen are not applied at rates that exceed the agronomic needs of the soil (regular soil testing, nutrient management planning).

- Exclude livestock from rivers and streams and re-establish naturally-vegetated buffers. Direct access to the stream by livestock can contribute to soil loss and enhanced mobilization of phosphorus, *E.coli* and other pathogens as river flows increase and inundation becomes more likely.

- Adhere to existing stormwater regulations. Implement enhanced stormwater ordinances at the municipal level to provide more stringent controls on stormwater runoff for development projects that fall under the thresholds which trigger implementation of stormwater management practices (i.e., Act 250 review, Stormwater Management Rule).

- Separate stormwater and sewer treatment systems.

- Improve management of stormwater runoff and reduce erosion along road ditches and at culvert outlets. Road maintenance practices to mitigate for stormwater and sediment runoff may include: stabilization of road surfaces (different gravel materials), improvement of roadside ditches (excavation, stone lining and/or seeding and mulching), alternative grading practices (turnouts, check-basins); re-orientation of culvert crossings; protection of culvert headers; and gully stabilization.

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[6] VT Dept of Forests, Parks & Recreation (2009), http://www.vtfpr.org/watershed/documents/Amp2009pdf.pdf

[7] VT Agency of Agriculture (2006), http://www.vermontagriculture.com/ARMES/awq/AAPs.htm

2. Earlier Thaw Dates and Seasonal Shift in Streamflows

Warming temperatures are leading to earlier thaw dates on Vermont rivers, lakes and ponds as well as earlier thaw dates for snowpack in the mountains. Earlier thaw dates and changing precipitation patterns have caused streamflows to shift seasonally. Average monthly flows in January and March, as well as July, August, and October through December, have increased while average monthly flows in April and May have decreased.

A majority of the total annual flow in Vermont rivers occurs from ice-out to late spring in a typical year (Shanley & Denner, 1999; Hodgkins & Dudley, 2011). This phenomenon is due to the occurrence of spring rains falling on saturated or frozen ground (accelerating runoff), melting of the snow pack stored in higher elevations, and low evapotranspiration rates prior to leafing of deciduous vegetation in the cool spring temperatures. Streamflows typically decline from May through September, as snowmelt ends, vegetation leafs out and evapotranspiration rates increase with heating through the summer months. River levels reach their lowest level in August or September, except when influenced by rains from a summer thunder storm or tropical system. River levels rebound somewhat in the fall with decreasing evapotranspiration rates as temperatures decline, leaves drop, and vegetation enters dormancy. Fall rains are common and can saturate soils, leading to increased runoff and higher river levels. It is common for tropical storms or hurricanes to result in high peak flows during fall months. Winter flows are generally low, since precipitation falls as snow and accumulates on the land surface as a result of below-freezing temperatures. Ice forms on lakes and ponds and over slower-moving water in rivers, until warming temperatures bring spring thaws and the cycle begins again.

Since climate changes will affect temperature and rainfall patterns as well as evaporation cycles in complex ways, flows in Vermont rivers are expected to shift seasonally. In winter months, a greater proportion of precipitation is expected to fall as rain or freezing rain rather than snow, since winter temperatures are rising (0.9°F per decade) twice as fast as summer temperatures (0.4°F per decade) based on records from 1960 through 2010 (Betts, 2011b). Warmer winters will lead to reduced accumulation of snow during some years. Less snowpack may mean less runoff during the late winter/early spring thaw. This effect may be offset by increased rains falling on frozen ground, leading to greater runoff. However, if winter temperatures rise to levels that decrease the duration of frost conditions by late in the century, runoff may be moderated by increases in soil infiltration – as long as soils do not become saturated by a rain event.

2.1 Historic Trends

Length of the frozen condition on Vermont lakes is decreasing by seven days per decade, as freeze-up has occurred four days later per decade and ice-out has occurred three days earlier per decade based on records from 1970 through 2010 (Figure 5.4) (Betts, 2011b).

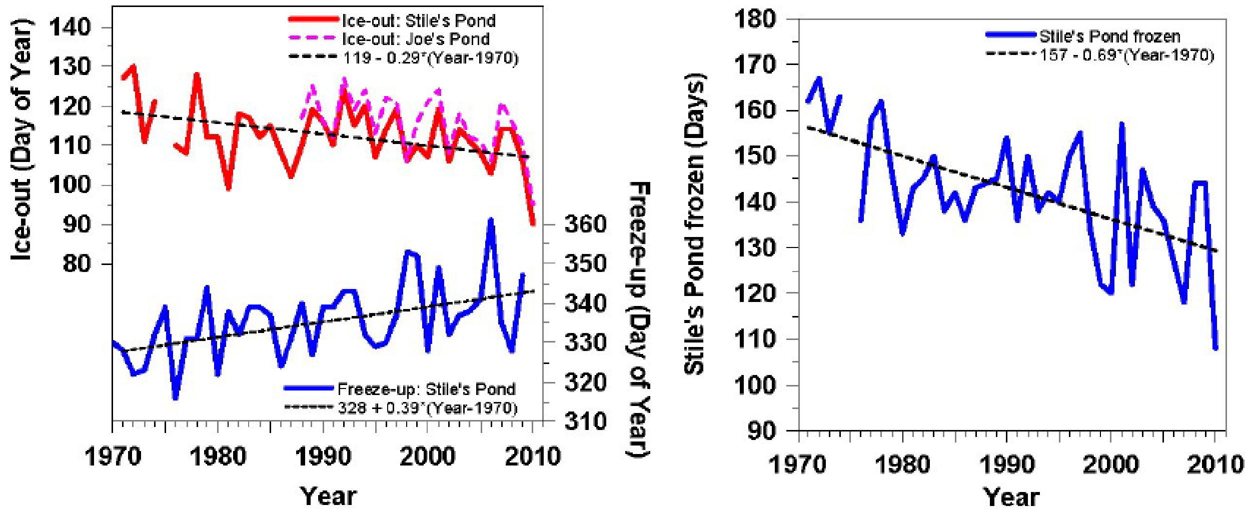
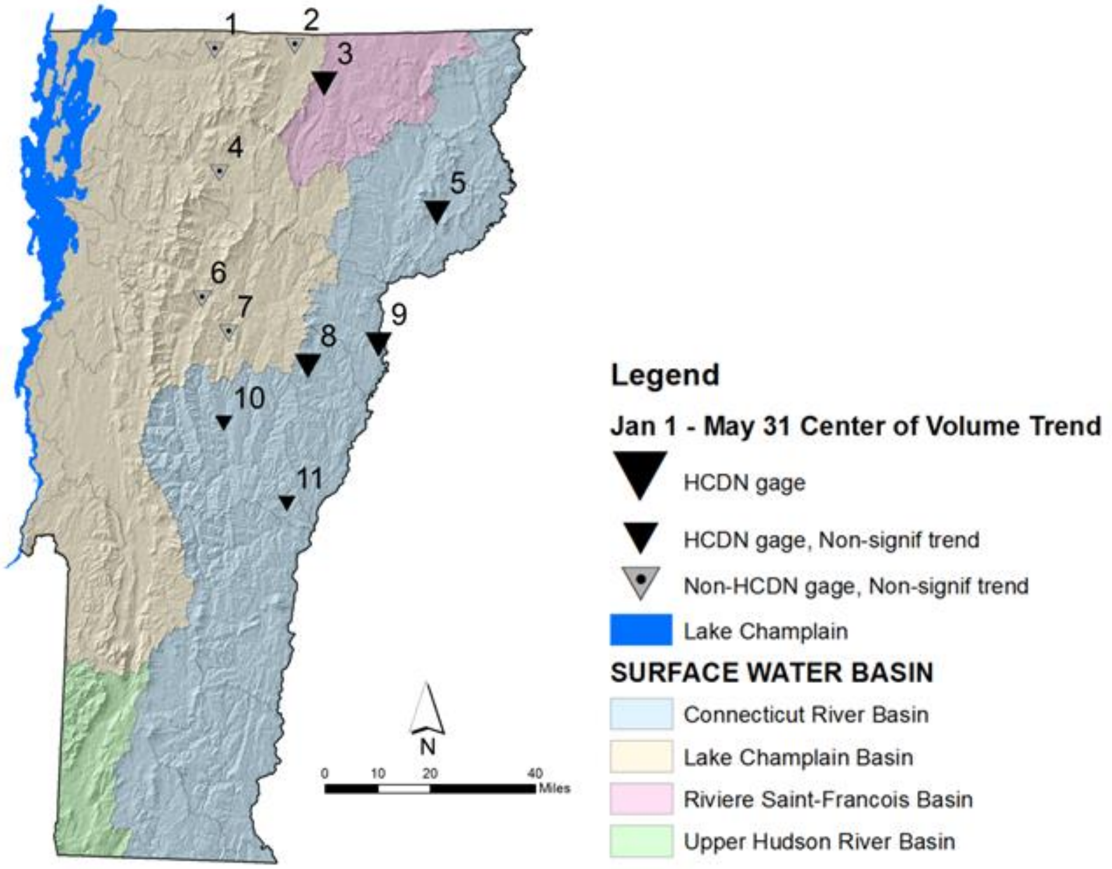


Figure 5.4. Historic ice-out and freeze-up trends on select Vermont ponds, 1970 to 2010. Excerpted with permission, from Betts, 2011b.

The effects of earlier snowmelt on streamflow have been demonstrated by Hodgkins *et al.* (2003) for several New England rivers in the HCDN. To evaluate for a potential shift in the distribution of flows through the seasons, they calculated the center-of-volume (COV) date for the winter/spring season (January 1 to May 31) in each year. A COV date represents the day on which one half of a river's total flow volume for a given time period of analysis passes by the gaging station. Hodgkins et al. (2003) found that the winter/spring COV of streamflow has shifted to earlier dates over the last three-quarters of the 20th century. From 1971 through 2000, the winter/spring COV date has come earlier by 1 to 2 weeks in those watersheds particularly influenced by melting snowpack. These shifting winter/spring COV dates were correlated to rising March and April air temperatures and increasing January precipitation. In a related study, Hodgkins and Dudley (2006) found significant increases in monthly average streamflow for New England rivers in the months of January, February and March over a period of record from 1953 to 2002, whereas May average runoff decreased at a number of stations over the same time period.

Figure 5.5 depicts COV trends recently calculated for eleven Vermont rivers, each of which are at sufficient elevation and latitude as to be particularly affected by snowmelt. Four of the eleven gaging stations demonstrated statistically significant decreasing trends in the winter/spring COV date. If trends in these four gages are examined more closely over equal lengths of record from 1959 through 2012, they indicate that the winter/spring COV date has come earlier by approximately 10 days (Figure 5.6). The other HCDN and non-HCDN gages also exhibited a decreasing trend in winter/spring COV, though not statistically significant.



No.	USGS Station	HCDN	Description	Years of Record	Trend	p-value
1	04293500		Missisquoi River Near East Berkshire, VT	92	-	0.238
2	04293000		Missisquoi River Near North Troy, VT	80	-	0.228
3	04296000	✓	Black River at Coventry, VT	61	-	**0.015**
4	04292000		Lamoille River at Johnson, VT	84	-	0.110
5	01134500	✓	Moose River at Victory, VT	65	-	**0.042**
6	04288000		Mad River Near Moretown, VT	84	-	0.102
7	04287000		Dog River at Northfield Falls, VT	77	-	0.127
8	01139800	✓	East Orange Branch at East Orange, VT	54	-	**0.024**
9	01139000	✓	Wells River at Wells River, VT	72	-	**0.020**
10	01142500	✓	Ayers Brook at Randolph, VT	73	-	0.113
11	01144000	✓	White River at West Hartford, VT	96	-	0.255

Figure 5.5. Historic trends in winter/ spring Center of Volume dates for select Vermont rivers. A negative trend (down arrow) indicates the COV date is moving earlier in the year. Trend is statistically significant (p<0.05; Mann-Kendall) for four of the eleven rivers. (Guilbert & Underwood, 2013, unpublished data; after Hodgkins et al., 2010).

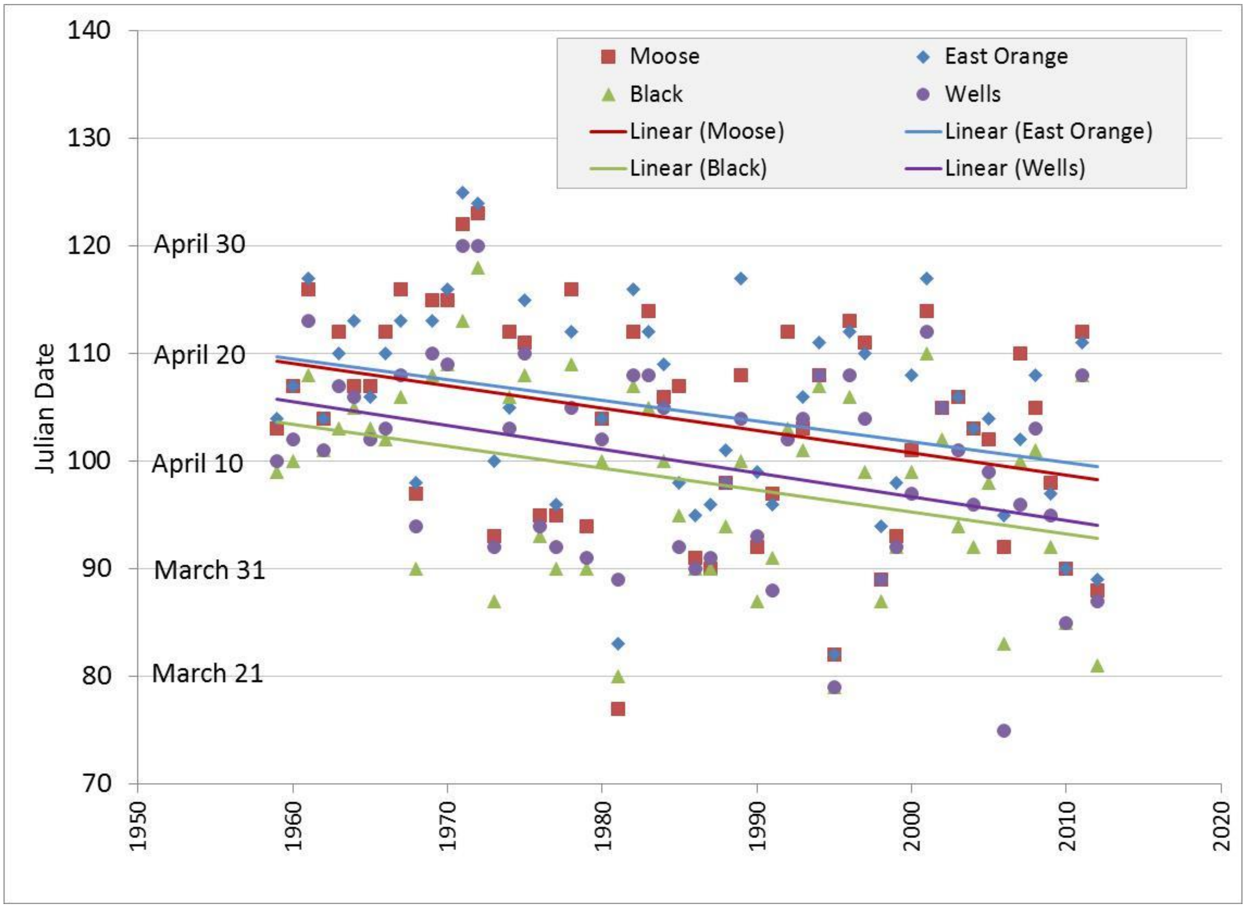


Figure 5.6. *Winter/Spring Center of Volume (Jan 1 through May 31) dates for years 1959 through 2012 for four Vermont HCDN gages for which a decreasing trend was statistically significant (p<0.05, Mann-Kendall). Remaining seven of eleven gages selected for analysis had similar decreasing trends that were not statistically significant.*

While flows in the latter half of the year represent a relatively small percentage of the total annual flow, seasonal shifts in precipitation are expected to result in increased streamflows in late summer and fall months. Based on recorded streamflows from eleven Vermont rivers (with record lengths ranging from 54 to 96 years through water year 2012), average flows in the late summer, fall, and winter months have increased. At least 9 out of 11 gages showed statistically significant (p<0.05, Mann-Kendall in all but one case that was p<0.10) increases in mean monthly discharge for the months of July, August, October, November, December, January and March (Guilbert & Underwood, 2013; unpublished data)

Similar results were suggested by an analysis of flows at six gaging stations in the Winooski River basin. Hackett (2009) found that monthly average discharge increased in August, October, November and December for the period from 1937 through 2005. These streamflow trends were correlated with increasing precipitation trends recorded for the same period.

2.2 Projected Trends

Climate projections for the Lake Champlain Basin indicate that the number of freezing days per year will decrease "from an average of 116.5 days during the base period [1970-1999] to 85.2 days by midcentury [2040-2069] and 71.7 days by late century [2070-2099]." (Guilbert *et al*., 2013). On average, the number of days in winter (December, January, and February) with snow coverage is projected to decrease by 5 days by 2100 in the Northeast (Hayhoe, et al 2007).

Based on climate models (and assuming high emission scenarios), Hayhoe *et al*. (2007) project a "tendency toward more streamflow in winter and spring, and less in summer and fall" for rivers of the Northeast, particular in northern latitudes where snowmelt has a strong influence on river levels in winter and spring months. Peak spring streamflows are projected to occur 5 to 8 days earlier by the middle of the century and 10 to 15 days earlier by century's end (Hayhoe *et al.,* 2007). This phenomenon is related to earlier thaw dates driven by warming winter temperatures. Variability in streamflow throughout the year will also increase; there will be higher, high flows and lower, low flows in the mix. A 40 to 70% increase in the probability of high flows is projected under assumptions of high GHG emissions (Hayhoe, *et al*., 2007) (Emissions scenarios are addressed in Chapter 1).

2.3 Impacts

Impacts of earlier winter thaw dates on the hydrologic cycle are difficult to predict and will be highly variable. In a typical year, the melting of snowpack in the Vermont mountains is a gradual process, and meltwaters are available to recharge groundwater, wetlands, lakes and reservoirs. Groundwater is then available to sustain base flows in our rivers during the later summer months. If climate change brings a thinner snowpack and reduced duration of snow cover in the winter months, it is possible that frost will penetrate deeper and persist for longer average durations with the absence of the insulating effect of snow cover. Presence of frost limits infiltration and, along with more rapid melting of the snowpack driven by warmer temperatures and increased frequency of rain-on-snow events, can be expected to increase volumes of runoff (Shanley & Chalmers, 1999). With this accelerated runoff to streams, it is possible that recharge to groundwater will be reduced. If less groundwater is available to sustain baseflow conditions in Vermont rivers, these conditions may contribute to a longer duration of summer dry periods. On the other hand, eventual warmer winter temperatures by century's end and reduced duration of frost may encourage infiltration of rain and snowmelt where presence of frost deep in the soil would ordinarily have limited infiltration.

As streamflows are projected to increase and shift seasonally, we may see changes in the distribution, composition, and suitability of instream habitats that affect the health and survival of fish and other aquatic organisms. Changing flow patterns may be especially impactful to species whose life cycles are dependent on the timing of spring flows, such as spring-spawning fish (Rustad *et al*., 2012).

On Vermont rivers, the earlier timing of ice-out, combined with an expected shift to earlier and high-magnitude winter flows, may result in earlier timing of ice-jams (Figure 5.7) and associated flooding (Prowse & Beltaos, 2002). The location and magnitude of ice jam floods is difficult to predict. Flooding effects are localized and lead to sudden erosion and inundation in "break-out" events.

Ice jam flooding can scour the channel margins impacting riparian vegetation and habitats, as well as affecting the dynamics of nutrient and organic matter cycles. On the other hand, localized outburst flood events caused by ice jams may introduce sediment, nutrients and organic matter into disconnected floodplain environments, thereby benefitting some riparian species (Huntington *et al.,* 2009).

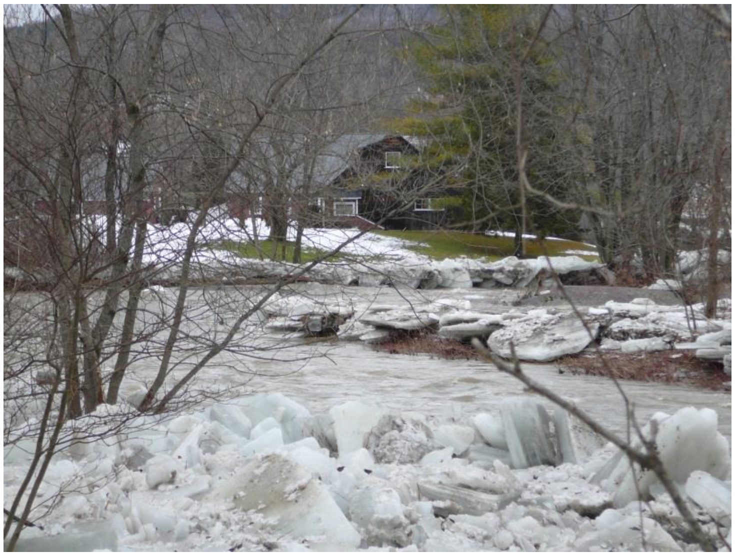


Figure 5.7. *Ice jam on the Lewis Creek in Charlotte floods the Lewis Creek Road and Spear Street Extension and adjacent residence during a January 2010 thaw. Photo credit: Kristen Underwood*

Earlier thaw dates on lakes and ponds could influence the timing of seasonal turnover and duration of intervening thermal stratification in deeper water bodies such as Lake Champlain. Turnover is a process of lake mixing that is driven by seasonal (fall and spring) temperature changes. Between mixing events, deeper lakes become thermally stratified with the cooler, denser water sinking to the bottom and warmer, less dense water at the surface. If spring mixing occurs earlier in the year, as a result of earlier ice-out, and there is a prolonged period of summer stratification, there could be a potential for enhanced oxygen depletion by late summer in the deepest parts of the lake. These hypoxic conditions could reduce phytoplankton abundance and impact other organisms that depend on phytoplankton as a food source (Stager & Thill, 2010).

Earlier thaw dates and seasonal shifts in streamflow may also impact the built environment. Given a legacy of development in narrow river valleys, Vermont communities will be susceptible to ice-jam flooding which can scour streambanks and damage adjacent roads, bridges, culverts and other structures in the floodplain. Freeze/thaw variability will increase damage to roads and other building materials. Community and domestic water supplies may be increasingly at risk near the end of the century, where replenishment of groundwater and reservoirs/ lakes is reduced as a result of reduced snowpack (and drier summer conditions). There may be an increased likelihood of groundwater well interference in more densely populated areas.

2.4 Opportunities to Build Resilience

- Avoid placing new infrastructure in high-risk ice-jam flood areas.

- Consider relocating infrastructure out of the floodplain.
- Where roads and infrastructure cannot reasonably be relocated outside of high-hazard areas, seek opportunities to restore flood plains upstream of developed areas, to shed ice and attenuate flood peaks.
- Design roads to be periodically overtopped by ice and flood waters, with appropriate emergency management plans in place to control traffic and ensure public safety during these flood events.

3. Flooding Projected to Intensify

High flows are larger in magnitude and are occurring more frequently, often in the winter months associated with earlier thaw dates for snowpack. In the coming decades, climate models project that a greater fraction of winter precipitation will fall as rain or freezing rain rather than snow, leading to rain-on-snow events and rain on frozen ground, with associated flooding. Up to an 80% increase in the probability of high flows is projected under assumptions of high green-house-gas emissions by the end of the century.

While up to one half of the total annual flow for Vermont rivers typically occurs between ice out and mid-May (Shanley & Denner, 1999), individual storm events can account for between 5 and 15 % of the total annual flow. Often the peak storm in a given water year is coincident with snowmelt in the late winter or early spring, but (more rarely) the peak annual event can also occur during a summer thunderstorm, or a late fall hurricane, for example.

3.1 Historic Trends

Records for rivers in New England, including Vermont rivers in particular, indicate a rise in the magnitude of the annual peak discharge over the last several decades (Hodgkins & Dudley, 2005; Collins, 2009; Huntington *et al.,* 2009). This finding is consistent with an observed increase in high-intensity and high-magnitude precipitation events in New England for a similar time frame (Karl & Knight, 1998; Groisman, *et al.,* 2001). Average annual precipitation in the Northeastern United States has increased approximately 3.3 inches over the 100-year period from 1900 to 2000 (UNH Climate Change Research Center, 2005). The frequency and number of intense precipitation events (defined as more than two inches of rain in a 48-hour period) has also increased, particularly in the last quarter of the 19th century (UNH Climate Change Research Center, 2005). This finding is notable, considering that forest cover has been regenerating across much of the New England region over this time period (Foster *et al.,* 1998; Thompson & Sorenson, 2002) – a change that would be expected to moderate flood peaks through effects of increased interception, infiltration and evapotranspiration.

This increasing trend in peak streamflows becomes more pronounced after 1970 (Collins, 2009; McCabe & Wolock, 2002)**.** The number of days per year with sustained high flows also appears to be increasing in some Vermont rivers (Figure 5.8).

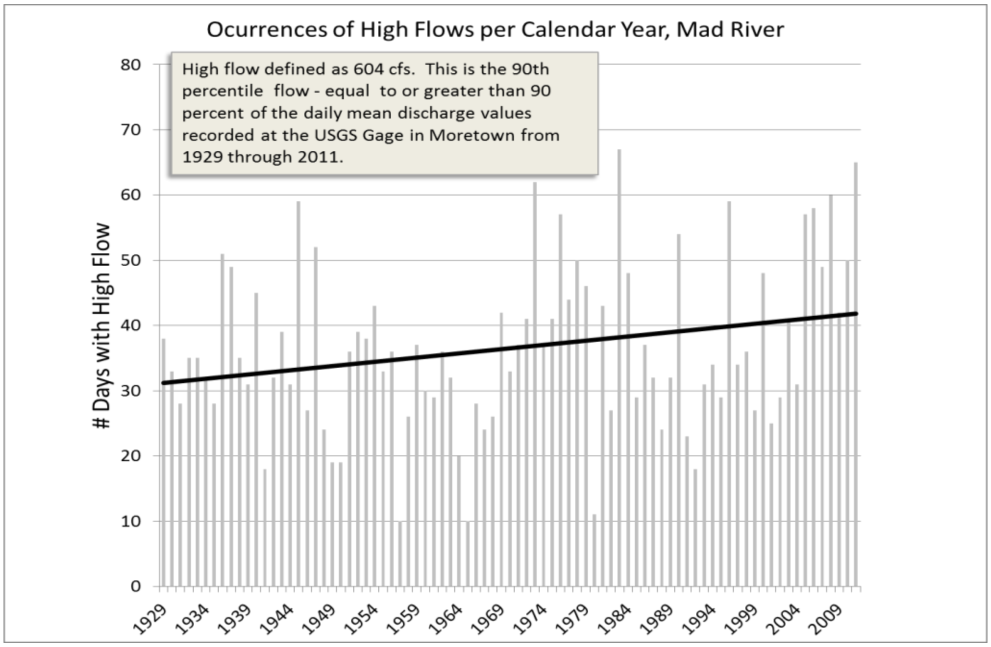


Figure 5.8. *Historic trend in frequency of occurrence of high-flow events at the USGS gage on the Mad River in Moretown, VT. (p<0.05; Mann-Kendall)*

3.2 Projected Trends

Climate projections suggest that, in winter months, a greater proportion of precipitation is expected to fall as rain or freezing rain rather than snow, leading to rain-on-snow events and rain on frozen ground (Frumhoff *et al*., 2007). The date of peak spring flow is projected to move earlier in the year as temperatures rise, advancing by more than 10 days by the end of the century (Frumhoff *et al*., 2007). A 40 to 80% increase in the probability of high flows is projected under assumptions of high GHG emissions (Hayhoe *et al*., 2007; Frumhoff *et al*., 2007).

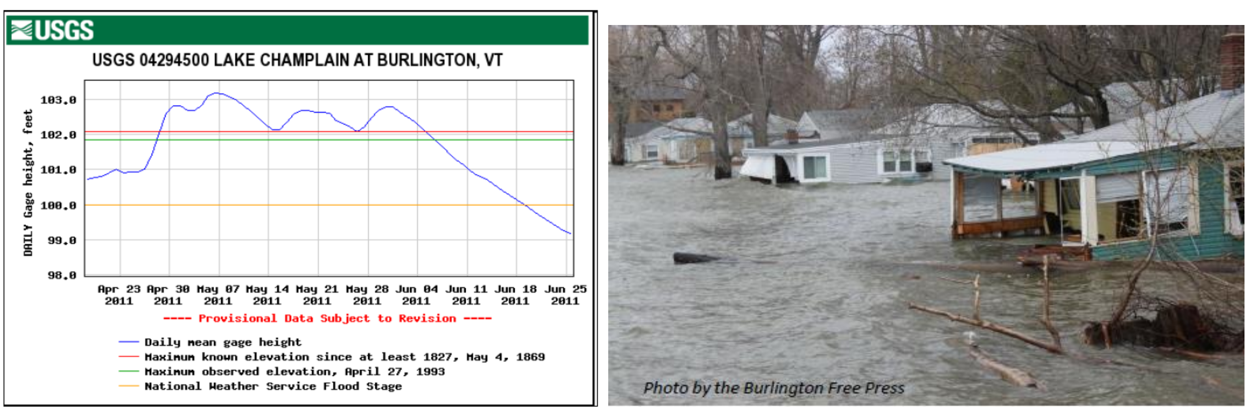


Figure 5.9. *Impacts of flooding on Lake Champlain, Spring 2011. (A) Lake Champlain exceeded the historic flood stage of record from April through June of 2011 as a result of heavy spring rains which fell on record snow packs. Historically, water levels in Lake Champlain have ranged from a low of 92.6 to 101.9 feet (USGS, 2009). A new record flood stage of 103.2 ft was established on May 6, 2011. (B) Flooding impacted shoreline properties around the lake resulting in Federal disaster declarations for Vermont (and New York) counties.*

3.3 Impacts

Expected increases in the intensity and amount of precipitation (Frumhoff *et al.,* 2007), paired with warmer temperatures, will mean that flooding will intensify along Vermont's river valleys and shorelines. The flood events of the last 20 years including spring flooding of 2011 and the catastrophic Tropical Storm Irene in August of 2011 are harbingers of things to come (Figures 5.9 and 5.10).

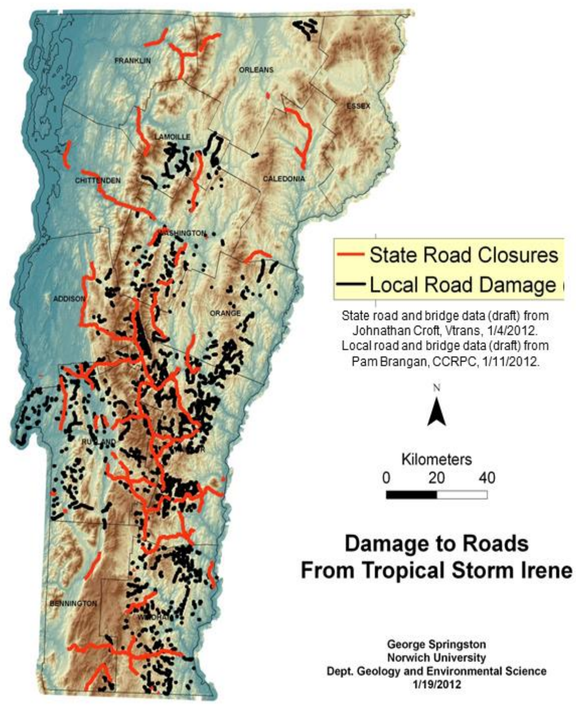


Figure 5.10. *During Tropical Storm Irene (August 28-29, 2011) more than 500 miles of state roads and 200 bridges were damaged. Town transportation infrastructure was also heavily damaged, including more than 2800 road segments, 280 bridges, and 960 culverts (Pealer, 2012). Map used with permission, G. Springston, Norwich University.*

Historically, agricultural and developed land uses have modified the Vermont landscape in ways that reduce flood resiliency. Pavement, rooftops and other impervious surfaces, speed runoff to receiving waters. Vegetation has been removed that might otherwise offer an attenuation of floodwaters. Wetlands have been converted to ditched, cultivated fields (with an associated loss of microtopography). Road and driveway networks and associated ditches intersect the stream network in multiple locations, delivering stormwater, sediment and debris.

Communities have been established along river banks and shore lines. Floodplains functions have been constrained by the construction of buildings, roads and other infrastructure. Streams and rivers have been ditched, channelized, straightened, bermed and armored and in many locations are now disconnected from their floodplains (Kline & Cahoon, 2010).

3.3.1 Water Quality

On the one hand, greater water volumes may offer greater assimilative capacity for some point sources of pollutants, such as wastewater treatment effluent, a failing septic system or illicit discharge. By and large, however, more frequent and intense floods will generate more nonpoint sources of pollutants, including sediment, pathogens, toxins and nutrients (Figure 5.11).
Higher lake levels induced by flooding will lead to greater shoreline erosion from wave action. Aging or non-maintained septic systems in close proximity to lake edges can be a source of nutrient loading and pathogens.

Excess sediment production can result from channel reaches that are undergoing active adjustment in response to a history of manipulation, sediment and/or flow alterations – this condition will be exacerbated by flooding events. Eroding streambanks have also been identified as a contributing nonpoint source of phosphorus in rivers and streams of Vermont where there is a legacy of phosphorus in floodplain soils (Langendoen *et al*., 2012; DeWolfe *et al*., 2004).

Increased turbidity from streambank erosion and overland delivery of sediments during flooding will also impact aesthetics and recreational uses of our lakes, ponds and reservoirs (Figure 5.12).

Figure 5.12 . *Lake Rescue, Ludlow, VT; view to south; September 2011. Following Tropical Storm Irene (August 2011), turbidity persisted for several months in Lake Rescue and other instream lakes along the upper Black River in Windsor County. Photo credit: Mansfield Heliflight*

3.3.2 Ecosystems

Increased flooding will impact natural habitats in various ways.

- Changes to shoreline wetland and littoral zone habitats where lake levels continue to show rising trends; flooding may give fish access to additional backwater habitats.
- Sedimentation in nearshore habitats affecting reproductive and rearing/larval fish
- Spread of invasives (Japanese Knotweed)

- Increased turbidity leading to water clarity issues that can reduce light penetration and impact productivity of aquatic organisms.

3.3.3 Agriculture

On agricultural lands, increased flooding will result in more frequent crop losses from inundation and erosion where fields are maintained close to rivers.

3.3.4 Built Environment

Increased flood intensity and frequency will cause:

- Repeat flood damages to transportation networks (roads, railroads, bridges, culverts) which share narrow valleys with rivers (Figure 5.13).

Figure 5.13. Route 4 washout along Mendon Brook, Mendon, Vermont.
Source: Mansfield Heliflight, www.mansfieldheliflight.com/

- Repeat flood damages to residential/commercial/municipal buildings & infrastructure located in close proximity to rivers and lakeshores.
- Inundation flood damages to lake-side properties.
- Damages to instream dams on Vermont rivers and potential for catastrophic breach during flooding.

- Damages to and releases from wastewater treatment facilities.

3.4 Opportunities to Build Resilience

Many mitigation / adaptation strategies are possible to address the expected increased intensity and frequency of flooding along Vermont rivers and shorelines.

3.4.1 Ecosystems

- Implement river corridor protection and management strategies to manage toward a more stable and flood-resilient condition of Vermont's rivers and floodplains. A river in dynamic equilibrium, connected to its floodplain, with a naturally-vegetated corridor can provide many important ecosystem services for our natural and built communities, namely:
    - Attenuation of flows to reduce the peak and intensity of downstream floods;
    - Sediment storage, in river meanders, the floodplain, and in riparian wetlands and flood chutes;
    - Attenuation, transformation, and uptake of nutrients such as phosphorus and nitrates in riparian wetlands and the floodplain;
    - Improved diversity of channel bedforms and riparian landforms (pools, riffles, eddies, connected wetlands) which help to regulate water temperatures and provide habitat and refuge areas for riparian and aquatic species;
    - Improved filtering and treatment of particulates and contaminants contained in storm flows; and
    - Increased recharge to groundwater (which in turn increases base flows of the river during drought conditions).
- Restore naturally vegetated buffers along rivers, lakes and wetlands.
- Restore channel-contiguous wetlands for their flood/sediment/nutrient attenuation functions (Callout box: Otter Creek)

3.4.2 Agriculture

- Implement changes in cropping practices to reduce concentrated runoff (and fine sediment and nutrient loading) to drainage ditches, road ditches, surface swales, inundation areas, wetlands lake edges and river channels. Possible measures include cover cropping, crop rotation, filter strips, grass buffers, interseeding, and no-till options in the fall of the year.

- Exclude livestock from stream channels. Fencing livestock out of the river reduces channel trampling (and nutrient / *E.coli* inputs) and allows trees and other native species to re-vegetate the channel margins.

- Identify more stringent nutrient management practices in saturated runoff-contributing areas (RCAs). Where these RCAs overlap with land uses that involve fertilizers or manure, manage nutrient applications to prevent mobilization of nutrients and sediments during snowmelt and precipitation events. In many locations, RCAs extend to distances from the channel banks that exceed default buffer widths specified in regulations (e.g., AAPs) or existing management agreements (e.g., nutrient management plans).

- Modify AAPs to address the expected increase in runoff and inundation and erosion flooding over coming decades.

- Consider taking vulnerable (frequently-flooded), and marginally-suitable lands (with uncertain yields) out of agricultural production – with the support of various state-and federally-funded cost-share programs.

3.4.3 Built Environment

- Refrain from future developments and infrastructure in the river corridor to minimize future fluvial erosion losses. This can be accomplished through conservation strategies or local planning and zoning strategies.
- Update and improve the delineation of risks from erosion hazards and inundation flooding along Vermont's rivers – to incorporate channel and floodplain changes that have occurred during flooding of the last few decades and to address future climate-driven risks of flooding.
- Where practical, and where risks to human safety are minimal, remove berms or other constraints along river channels and floodplains to create opportunities for sediment and flow attenuation – particularly upstream of developed areas.
- Remove low-functioning or abandoned dams
- Where practical, move infrastructure (e.g., roads, buildings, wastewater treatment plants) outside of floodprone areas.
- Flood-proof public buildings when relocation is not technically or economically feasible.
- Where necessary, and as regulated through the permit process, limited sediment dredging from lakes may be required to maintain navigation channels or recreational areas.
- Employ low-impact development strategies that minimize stormwater runoff and increase infiltration of rainwater and snowmelt.

    - Establish or Increase Minimum Lot Sizes
    - Establish or Reduce Maximum Lot Coverages / Minimize Percent Impervious
    - Minimize land disturbance / compaction during construction

- Prevent stormwater outfalls from crossing vegetated buffers and entering rivers and streams without treatment or energy dissipation.
- Specify maximum road and driveway widths.

▪ Design new bridge/culvert crossings with wider openings to pass flows, sediment, and woody debris without constriction.

1. Box 5.1 Otter Creek: Importance of conserving wetlands for flood attenuation

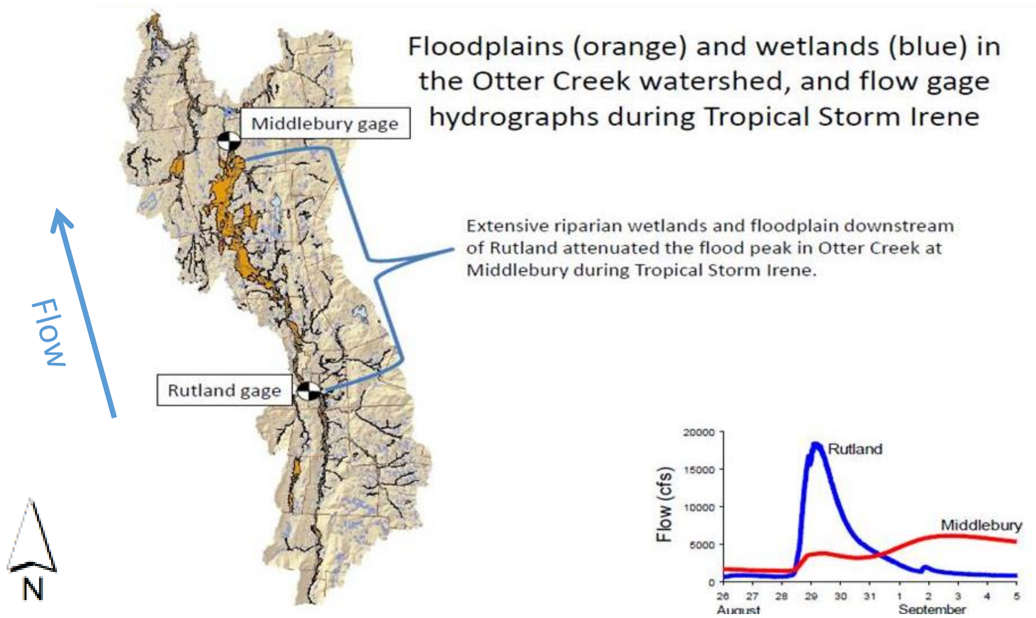


Figure excerpted with permission from the Otter Creek Basin Plan, VTANR, 2012
(flow in the Otter Creek is from south to north – upward on the page)

The role of riparian wetlands for flood attenuation was highlighted in the Otter Creek basin during Tropical Storm Irene in August of 2011. Streamflow on the Otter Creek at the Rutland gage (307 square mile drainage area) peaked at 15,700 cubic feet per second at 3 AM on August 29. Meanwhile further downstream in the watershed at the Middlebury gage (628 sq mi), flows were slow to rise and peaked well after the storm during the afternoon of September 2nd. The Otter Creek channel between the Rutland and Middlebury gages is surrounded by 8,700 acres of riverside wetlands and floodplain forests known as the Otter Creek Swamps – the largest forested swamp complex in New England. The Otter Creek spilled over its banks into the adjacent swamplands, which retained the floodwaters and slowly released them back to the river over several days following the storm. This attenuation of floodwaters spared the downtown communities of Middlebury and Vergennes from significant damages in Irene.

For more on this story visit http://www.youtube.com/watch?v=ucb-Y8iipng

4. Potential for Summer Dry Spells by Century's End

Warming temperatures and an expected increase in seasonal variability of rainfall and runoff may increase the potential for summer dry spells by century's end. Evidence suggests that Vermont rivers have sustained higher base flows during summer months over recent decades, in contrast to other parts of New England (coastal Maine) and the US. However, climate projections indicate an increased potential for dry spells in summer months by the end of the century, which could lead to extended periods of very low stream and lake levels and reduced recharge to groundwater.

Over a typical year, river flows reach minimum levels in July through mid-September. Precipitation rates are generally low, with the exception of an occasional convective or tropical storm. Evapotranspiration rates are high due to maximum vegetative productivity and higher summer temperatures. Soil moisture levels are low and groundwater reserves are near annual lows, resulting in minimal return flows to the river. When a summer thunderstorm or even a tropical storm passes through, rains are quickly absorbed by the soils or taken up by vegetation and less is available for runoff to rivers, lakes and ponds.

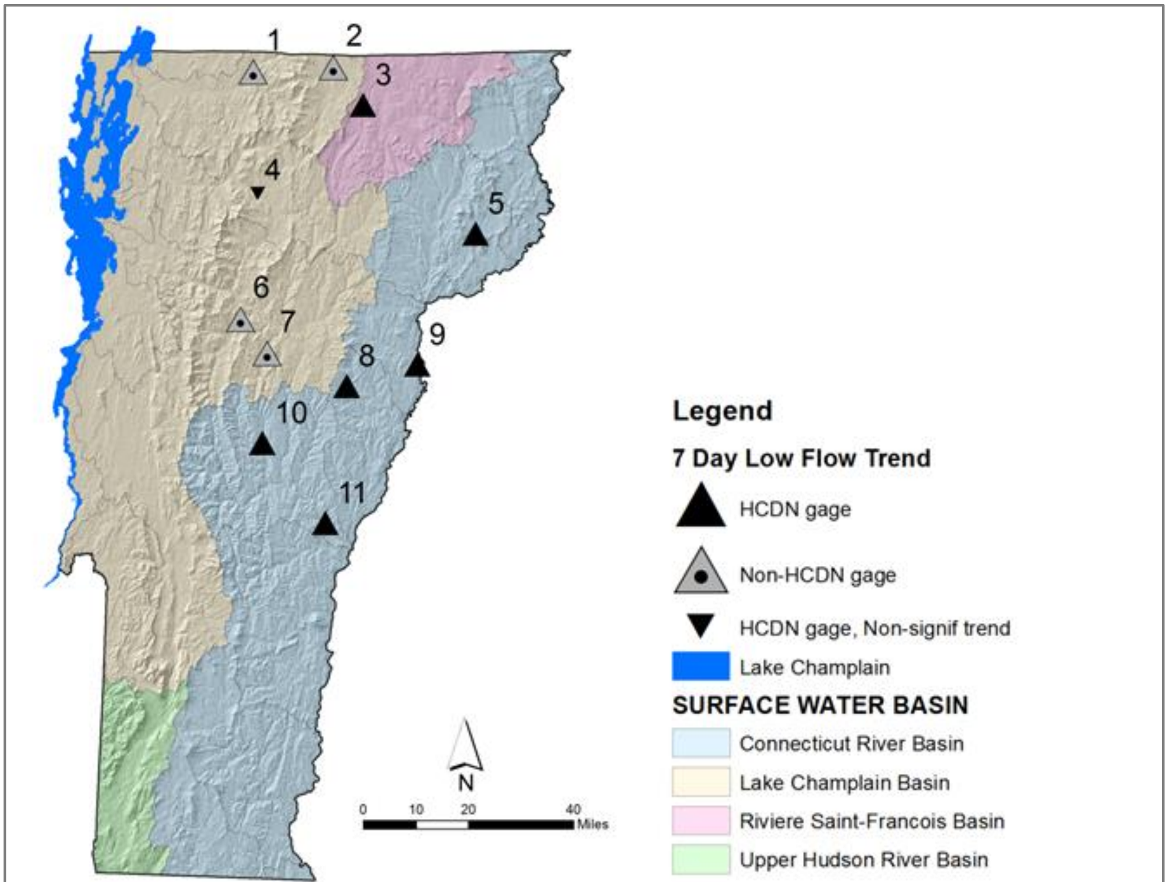
As precipitation patterns continue to shift and temperatures warm with changing climate, we can expect changes in the water balance. Higher-elevation (Green Mountains) and higher-latitude areas of Vermont (Northeast Kingdom) may be less impacted by warming temperatures. While the Champlain Valley may be particularly vulnerable (TetraTech, 2013) as it is generally warmer and drier than other regions of Vermont.

4.1 Historic trends

Historic data for Vermont (and New Hampshire) rivers indicate a rise in summer base flows from 1950 to 2006 that can be explained in part by increases in summer precipitation recorded in these regions (Hodgkins & Dudley, 2011).

Similar results were suggested by an analysis of flows at six gaging stations in the Winooski River basin for a study period from 1937 through 2003 (Hackett, 2009). Despite conversion of cleared lands to forested lands in the latter half of the 20th century (open fields decreasing from 23% to 9%, forest cover increasing from 72% to 82%), and the associated rise in evapotranspiration rates, base-flows in the basin showed an increasing trend. The increase in streamflows was strongly correlated to a 14% increase in precipitation over the period of record.

Ten out of eleven Vermont rivers evaluated indicate a similar positive trend (Figure 5.14) that is statistically significant ($p<0.05$; Mann-Kendall). One river (Lamoille) exhibits a negative trend that is not statistically significant. This Lamoille River gage may be influenced by operations at an upstream dam. August median flows for five Vermont HCDN gages are examined in more detail in Figure 5.15. The US Fish & Wildlife value of 0.5 cfs per square mile of watershed (Lang, 1999) has been adopted by the State of Vermont in its streamflow policy as an indicator of critical habitat for native fish. Trend lines in Figure 5.15 indicate that average low flows have been increasing in recent decades and are now above the 0.5 cfs per square mile threshold (though August median flow in any given year can still be well below this threshold).



No.	USGS Station	HCDN	Description	Years of Record	Trend	p-value
1	04293500		Missisquoi River Near East Berkshire, VT	92	+	**0.078**
2	04293000		Missisquoi River Near North Troy, VT	80	+	**0.0003**
3	04296000	✓	Black River at Coventry, VT	61	+	**0.002**
4	04292000		Lamoille River at Johnson, VT	84	-	0.457
5	01134500	✓	Moose River at Victory, VT	65	+	**0.005**
6	04288000		Mad River Near Moretown, VT	84	+	**0.00001**
7	04287000		Dog River at Northfield Falls, VT	77	+	**0.00003**
8	01139800	✓	East Orange Branch at East Orange, VT	54	+	**0.0004**
9	01139000	✓	Wells River at Wells River, VT	72	+	**0.066**
10	01142500	✓	Ayers Brook at Randolph, VT	73	+	**0.0001**
11	01144000	✓	White River at West Hartford, VT	96	+	**0.004**

Figure 5.14. *Historic trends in 7-day low flows for select Vermont rivers. Positive trend (upward arrow) indicates increasing discharge value. Negative trend (downward arrow) indicates decreasing discharge value. Positive trend is statistically significant (p<0.05; Mann-Kendall) for 10 out of 11 rivers. One river exhibits a negative trend that is not statistically significant.*

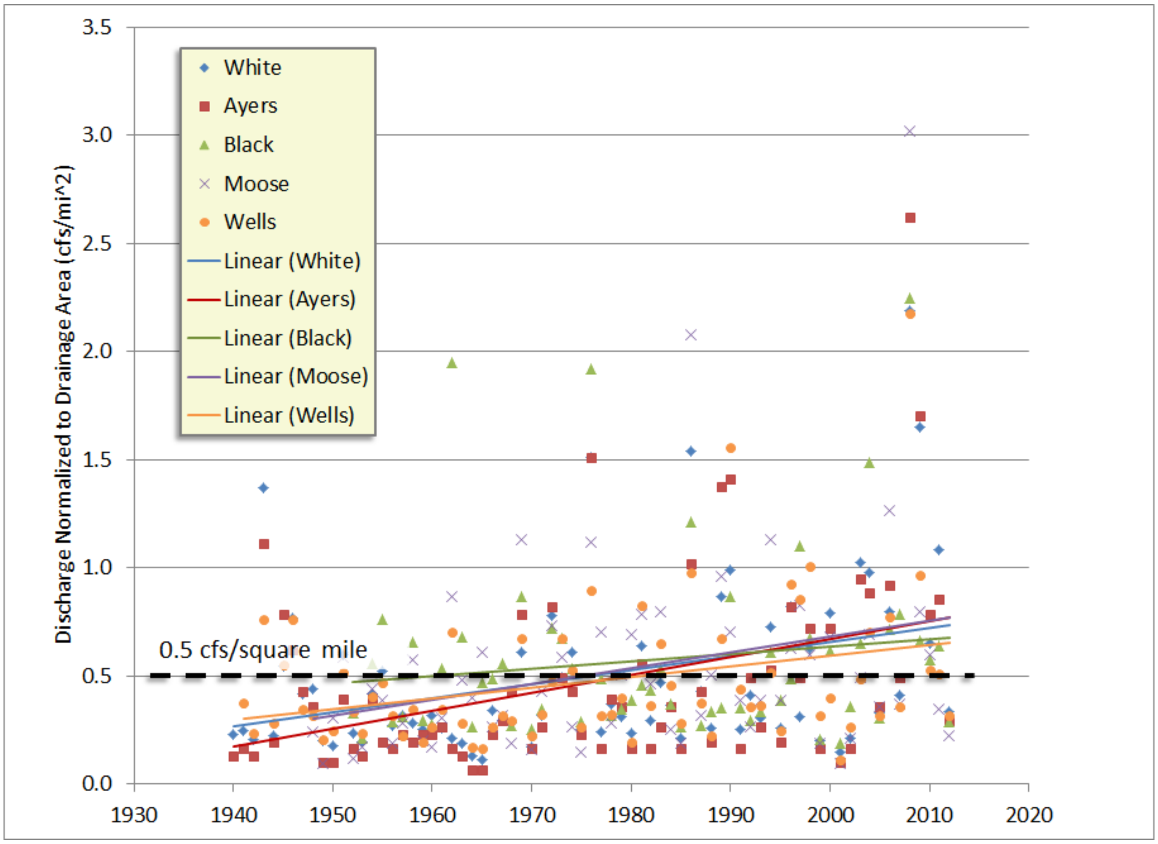


Figure 5.15. August median flows normalized to drainage area for five HCDN streamflow gages in Vermont. Trend lines indicate that average low flows have been increasing over the decades and are now above the 0.5 cfs per square mile threshold commonly adopted as an indicator of critical habitat for native fish.

4.2 Projected trends

Over the longer term, however, changing precipitation and runoff patterns are projected to result in lower summer baseflows, an extended low-flow period, and more frequent summer dry periods here in the Northeast (Frumhoff *et al.*, 2007; NEICA, 2006; Hayhoe *et al.,* 2007). Climate projections for the Northeast indicate, on average, that the summer low-flow period will arrive one week earlier in the summer and be sustained up to three additional weeks into the fall months (NEICA, 2006). Climate projections for the Lake Champlain basin suggest that, by late in the present century, average evapotranspiration rates will exceed average precipitation rates in the month of July, which could contribute to short-term dry spells (Guilbert *et al.*, 2013).

Increasing summer temperatures would be expected to increase evapotranspiration from vegetated land surfaces. If the amount of water lost to evaporation exceeds the amount of water gained through precipitation, this balance could reduce the amount of water that infiltrates to groundwater or runs off into rivers, lakes, and reservoirs. Watersheds with a higher percentage of lakes, ponds, and wetlands may be more susceptible to the effects of increased temperature on evaporation rates, leading to lower base flows (Hodgkins & Dudley, 2011). In general, recharge to groundwater would be expected to decrease under scenarios of increased summer temperatures and increased evapotranspiration rates.

4.3 Impacts

Low-flow periods in Vermont rivers are particularly critical for fish and other organisms that inhabit the river and streamside areas. Baseflows sustained by groundwater contributions are important for moderating water temperatures in the presence of elevated summer air temperatures and incoming solar radiation. Locations of groundwater seeps in the channel represent cooler-water inputs that offer refuge from warmer summer temperatures for fish. Baseflows are also critical for sustaining wetted channel margins to benefit aquatic insects, amphibians, reptiles, and other riparian organisms (Figure 16).

Figure 5.16. Wood turtles live and breed in riverside habitats and rely on Vermont streams for refuge and overwintering. The Wood Turtle has been designated a Species of Greatest Conservation Need (high priority) in Vermont's Wildlife Action Plan, and is a species of special concern in Vermont.

In the short term (early century), impacts to riparian and instream habitats may be moderated, given the observed increasing trend in baseflow (Figure 15). If climate projections hold true for the late century, and low-flow periods become more frequent, these species will experience increased stress as a result of reduced availability of suitable habitat. While it is relatively uncommon for Vermont stream reaches to dry up completely in the late summer months, such "losing reaches" may become more common in the late century, and river sections with suitable habitats may become increasingly isolated.

Shallower waters are warmed more quickly. Shallower pool depths and reduced contributions from cooler groundwater seeps will mean fewer refuge areas in the river network for cold-water species, including brook trout and freshwater mussels such as the eastern pearlshell.

As stream temperatures warm, the capacity to hold dissolved oxygen will be reduced. Cool, well-oxygenated waters are critical for many aquatic organisms, such as brook trout. If late-century increases in low-flow conditions are realized, cold-water species in particular will be impacted through reduced availability of cooler, oxygen-rich waters.

In Vermonts deeper lakes, greater evaporation rates caused by increased summer air temperatures could result in lower than normal lake levels into early fall weeks. "Rising surface water temperatures may increase the stability and duration of warm-season stratification …, potentially making [them] more susceptible to nuisance phytoplankton blooms and low-oxygen ('hypoxic') conditions" (Stager & Thill, 2010). Warmer lake temperatures may lead to progressive loss of cooler, deep water zones with particular impacts to cold-water species including lake trout (Stager & Thill note that there is no clear record of this trend to date, although records are sparse).

In wetlands and vernal pools, water levels may decrease or dry up sooner due to increased evapotranspiration rates in summer months and the earlier timing of snowmelt. These changes may adversely impact breeding cycles and survival of reptiles and amphibians such as the wood turtle or the spotted salamander. "Acidic bogs are expected to be particularly vulnerable because of their specialized habitat requirements (cold climate, short growing season, and slow rate of decay of organic matter)" (TetraTech, 2013).

In general, productivity and abundance of aquatic organisms will be impacted by extended dry spells. Generalist species, that are more adaptable to changing conditions will be favored, while organisms more sensitive to warm temperatures, soil moisture deficits, and decreased streamflows will be more impacted. Particularly sensitive species will suffer physiological stress and possible mortality (Tetratech, 2013). Adaptive invasive species – both aquatic and land-based - may become more prevalent as their productivity out-competes native species. As a consequence, the species composition of aquatic and riparian habitats may change in ways that are not well understood.

The potential for increased dry spells and low-flow conditions will have water quality implications. In lakes, oxygen-poor conditions driven by warming trends and extended thermal stratification may drive bio-geochemical cycles that encourage greater release of dissolved phosphorus from lake sediments (Tetra Tech, 2013). Higher water temperatures can allow for greater incidence of mercury methylation. "Methylmercury impairs organ and nerve functions in vertebrates, and through bioaccumulation it can compromise the health of predatory fish as well as the people and animals that eat them." (Stager and Thill, 2010). During low-flow conditions projected for summer months, Vermont rivers will have a reduced assimilative capacity for receiving treated sewage or thermally-modified effluent. Toxins and nutrients will be more concentrated. Shallower water depths and higher temperatures in summer and early fall months may result in a greater likelihood of algae blooms in rivers and wetlands.

With increasing frequency of dry spells and drought near the end of the century, the quantity and quality of surface waters and groundwater may not be sufficient to meet human demand. Availability and reliability of water resources will be affected in complex and unpredictable ways.

Increased competition for limited water resources will necessitate greater cooperation among a variety of users (see Section 5).

4.4 Opportunities to Build Resilience

Several strategies are available to address the potential for increasing summer dry spells or even long-term drought by end of century.

- Conserve high-quality riparian habitats with intact forested buffers that offer habitat connectivity for aquatic and land-based organisms – with particular emphasis on higher-elevation, higher-latitude land areas.
- Improve aquatic organism passage of culverts to open up more cold-water areas for refuge by temperature-sensitive species (see Box 5.2).
- Remove unused or deteriorating dams, impoundments and diversion structures on Vermont rivers to increase habitat connectivity.
- Fill buffer gaps along river reaches and lake edges by planting native shrub and tree species to offer waterside shading. In addition to reduced water temperatures, tree buffers will provide organic matter and woody debris recruitment for aquatic and riparian habitats. A more robust riverside community will be more resilient in the face of other climate-induced stressors.
- Add large woody debris to restore pool/riffle habitat diversity (e.g., Battenkill River);
- Improve capacity and treatment at waste-water treatment facilities to reduce the nutrient and toxin levels in effluent discharged to rivers and lakes.
- Diversify farming practices toward crops and other endeavors that rely less on water and irrigation.
- Take measures to conserve water use at home, schools, businesses and industry (for example, use water-saving flow valves; water lawns and gardens during dawn and dusk hours to minimize loss of water to evaporation when sun is highest in the sky; collect rain water from rooftops in barrels to reuse for watering gardens; install rain gardens to collect rainwater and runoff to recharge groundwater).

♦ Employ low-impact development strategies that minimize stormwater runoff and increase infiltration of rainwater and snowmelt.

♦ Subject to state and local approvals, various sectors could consider diversion of surface waters to off-stream reservoirs during higher-flow times of the year so that water will be available during low-flow periods without direct impacts to river flows (e.g., Vermont ski areas have been following this approach for snow-making ponds)

♦ Promote forest cover and minimize impervious surfaces in headwaters and known groundwater recharge areas.

Box 5.2 – Reducing channel constrictions through installation of open-arch road crossings.

The US Forest Service recently installed an open-arch crossing for the Natural Turnpike road over the Sparks Brook, tributary to the Middle Branch of the Middlebury River, in the Green Mountain National Forest. In 2010, a bottomless arch was constructed to replace a small-diameter culvert that was undersized with respect to the bankfull width of the Sparks Brook channel. The bottomless arch and channel vicinity were designed in accordance with Vermont Fish & Wildlife guidance for passage of aquatic organisms (Stream Simulation Design). The open (bottomless) design permits more naturalized flow of water, sediment and woody debris, and opens up more cold-water habitat for refuge from an expected warming climate.

Photo credit: Kristen Underwood

5. Uncertain Impacts to Water Resources

Changing rainfall and runoff patterns will affect availability and reliability of water resources to a variety of Vermont sectors (e.g., agriculture, communities, tourism, energy) in complex ways.

Water is considered relatively abundant in the Northeast, and the quantity of water resources is generally not regarded as a limitation for use as much as potential quality issues. At present, Vermonters meet their water needs from a combination of groundwater and surface water sources. Figure 16 is excerpted from a recent USGS publication that summarized groundwater and surface water sources by category of use (Medalie & Horn, 2010). If thermoelectric power sources are not considered (Entergy Nuclear - Vermont Yankee Power Station in Vernon, Vermont, scheduled to close in 2014), groundwater and surface water sources represent 51%

and 49%, respectively, of the 100 million gallons of water extracted and used by Vermonters on average each day. Private and public community water system uses make up 63% of the total.

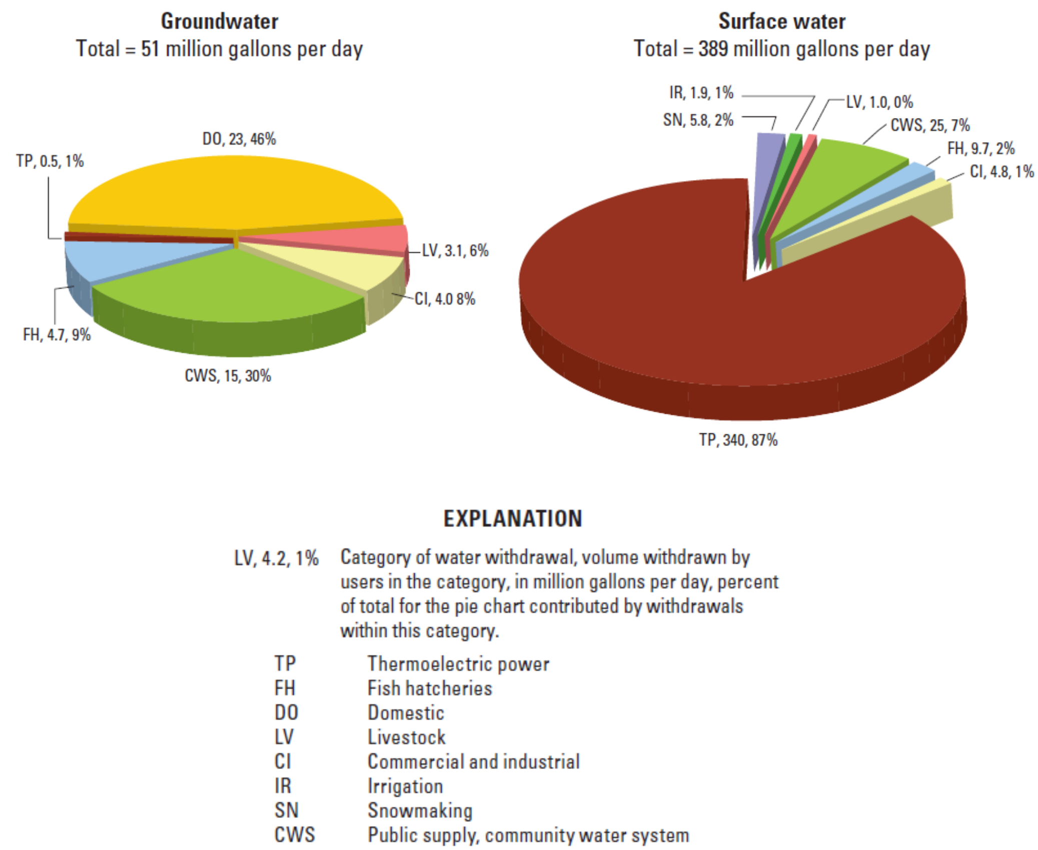


Figure 5.16. Groundwater and surface water withdrawals in Vermont by category of use. (Excerpted with permission from Medalie & Horn, 2010, USGS SIR 2010-5053).

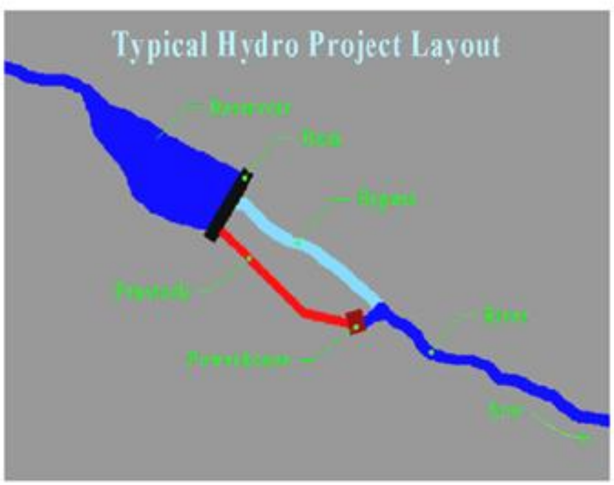
With expected late-century decreases in summertime baseflows, availability of groundwater and surface water may become more limited seasonally, as various sectors compete for their use. There may be increased demand on surface water resources from the agricultural sector to irrigate during short-term dry spells or droughts. Hydropower facilities may experience more frequent interruptions in service at times when river flows drop below minimum operating levels established in their federal and state permits (see Callout Box). Where permitted under state regulations, the ski industry may increase water withdrawals for snow-making to combat declines in thickness and duration of snowpack expected by late in the century. We may see a shift toward more groundwater use in general, which in turn could reduce baseflows in Vermont rivers. "[Surface] water withdrawals or other stream flow alterations may become more common, and human uses may compete with aquatic management needs." (Pealer & Dunnington, 2012).

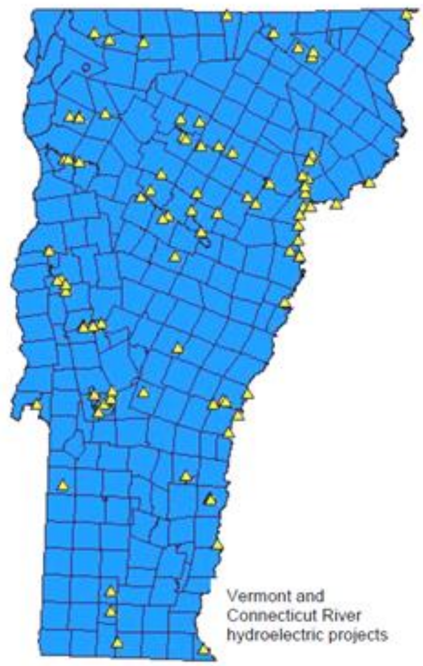
Vermont may be a receiving state for climate refugees as Northeast coastal populations are increasingly impacted by rising sea levels. As Vermont communities grow in size, there will be

Box 5.3 – Potential climate change impacts to Vermont's hydroelectric industry

"Presently Vermont has 84 operating hydroelectric plants. They are distributed throughout the state, and are owned by public and private utilities, electric co-ops, companies and individuals. The plants have a total generating capacity of 190 megawatts (MW), and produce on average 12 percent of Vermont's KWH load". (Renewable Energy Vermont, www.revermont.org.) State and federal regulations require that minimum stream flows necessary for the protection of instream habitats are provided in the river reach associated with a hydropower facility. The minimum required flow is unique to each facility and is based on the impacted length of the channel, as well as habitat and species present in the channel. Most hydropower facilities operate as "run-of-river" facilities, such that flows into the hydroelectric project equal flows leaving the project. There is typically a bypass segment of the river where flows are reduced since a portion of the flow is diverted through a penstock to turbines in the powerhouse. Regulation of minimum flows includes the bypass segment.

Excerpted with permission from *The Development of Small Hydroelectric Projects in Vermont* (VTANR, 2008)





With increasing potential for low flows by end of century, operations at these hydroelectric facilities may be curtailed for longer periods of time in order to meet minimum flow requirements. With more frequent high-flow events there will be a higher risk for catastrophic damages at these facilities, and accelerated build up of sediments (and reduced reservoir capacity) behind associated impoundments.

increasing demands on water supplies in support of various sectors, with possibility for inter-sector competition.

6. Summary Table Rating Quality of Information

Key Message #1/5

As average annual rainfall has increased in recent decades, average annual flows in Vermont rivers have increased. Based on climate model projections, average annual streamflows are expected to continue increasing in coming decades.

Evidence base:
Observed trends:

- New England / Northeast (Collins, Mathias J., 2009; Hodgkins and Dudley, 2005; Huntington et al, 2009; Lins & Slack, 2005)
- Vermont (Hodgkins et al.; 2010; Hackett, 2009; Guilbert & Underwood, 2013)

Forecasted trends:

- New England / Northeast (Huntington et al, 2007);
- Vermont ()

Uncertainties and data gaps: Efforts to improve the information base should address the coordinated monitoring of sentinel streamflow gaging sites. Monitoring is critical to tracking and quantifying impacts on climate change and the effectiveness of adaptation and mitigation strategies. Monitoring of the streamflow gaging network coordinated by USGS should be expanded and funded as a national and regional priority.

While forecasted trends are more uncertain, they provide an important basis for adaptive management and resiliency planning.

Assessment of confidence based on evidence: Very High

Key Message #2/5

Warming temperatures are leading to earlier thaw dates on Vermont rivers, lakes and ponds as well as earlier thaw dates for snowpack in the mountains. Earlier thaw dates and changing precipitation patterns have caused streamflows to shift seasonally. Average monthly flows in January and March, as well as July, August, and October through December, have increased while average monthly flows in April and May have decreased.

Evidence base:

Observed trends:

- New England / Northeast (Hodgkins et al, 2003; Hodgkins and Dudley, 2006; Huntington et al, 2009; Lins & Slack, 2005)
- Vermont (Betts, 2011b; Hacket, 2009; Guilbert & Underwood, 2013)

Forecasted trends:

- New England / Northeast (Hayhoe, et al, 2007);
- Vermont (Guilbert et al., 2013)

Uncertainties and data gaps:

None identified at this time.

Assessment of confidence based on evidence: High

Key Message #3/5

High flows are larger in magnitude and are occurring more frequently, often in the winter months associated with earlier thaw dates for snowpack. In the coming decades, climate models project that a greater fraction of winter precipitation will fall as rain or freezing rain rather than snow, leading to rain-on-snow events and rain on frozen ground, with associated flooding. Up to an 80% increase in the probability of high flows is projected under assumptions of high green-house-gas emissions by the end of the century.

Evidence base:

Observed trends:

- New England / Northeast: (Hodgkins & Dudley, 2005; Collins, 2009; Huntington et al, 2009; McCabe & Wolock, 2002)
- Vermont: (Hodgkins & Dudley, 2005; Collins, 2009; Guilbert & Underwood, 2013)

Forecasted trends:

- New England / Northeast: (Frumhoff et al, 2007; Hayhoe et al., 2007)
- Vermont ( )

Uncertainties and data gaps: Increased risk of floods is not easily quantified or communicated to the public. There is a need for re-evaluation and framing of flood risk in order to more effectively inform community planning, infrastructure design and maintenance, as well as risk to public safety and health.

Assessment of confidence based on evidence: High

Key Message #4/5

Warming temperatures and an expected increase in seasonal variability of rainfall and runoff may increase the potential for summer dry spells by century's end. Evidence suggests that Vermont rivers have sustained higher base flows during summer months over recent decades, in contrast to other parts of New England (coastal Maine) and the US. However, climate projections indicate an increased potential for dry spells in summer months by the end of the century, which could lead to extended periods of very low stream and lake levels and reduced recharge to groundwater.

Evidence base:

Observed trends:

- New England / Northeast (Hodgkins & Dudley, 2011;)
- Vermont (Hodgkins & Dudley, 2011; Hackett, 2009; Guilbert & Underwood, 2013)

Forecasted trends:

- New England / Northeast (Frumhoff et al, 2007; NEICA, 2006; Hayhoe et al, 2007)
- Vermont (Guilbert et al, 2013)

Uncertainties and data gaps: Impacts on groundwater aquifers may be highly variable. At present, groundwater in Vermont is not well characterized due to funding limitations. There is a need for additional assessment, particularly in more densely populated areas where future demands on groundwater are expected to increase.

Assessment of confidence based on evidence: Medium

Key Message #5/5	Changing rainfall, runoff and temperature patterns will affect availability and reliability of water resources to a variety of Vermont sectors (e.g., agriculture, communities, tourism, energy) in complex ways.

Evidence base:

Observed trends:

- New England / Northeast ()
- Vermont ()

Forecasted trends:

- New England / Northeast (Brekke, et al, 2009)
- Vermont (Medalie & Horn, 2010; Pealer & Dunnington, 2012)

Uncertainties and data gaps: Impacts on groundwater aquifers may be highly variable. At present, groundwater in Vermont is not well characterized. There is a need for additional assessment, particularly in more densely populated areas where future demands on groundwater are expected to increase.

Assessment of confidence based on evidence: High

CONFIDENCE LEVEL

Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Chapter 6: Forests

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Key Messages

- **Increased temperatures will lengthen growing seasons and increase suitable range for certain Vermont tree species like oak, hickory, and white pine, but decrease suitable range for cold-tolerant species like red spruce and balsam fir. Models project that by the end of the century, an oak-hickory forest could dominate the Northeast with spruce-fir forests being virtually non-existent, and maple-beech-birch forests persisting only in Maine.**
- **Alterations in precipitation cycles (wetter winters and extended dry spells in late summer/fall) will place more stress on important tree species such as sugar maple and red spruce, which have already experienced periods of decline in Vermont. Warmer temperatures will result in earlier bud burst and flowering periods for certain species, making them more susceptible to pests and pathogens.**
- **Increases in frequency and severity in natural disturbances as a result of climate change will affect Vermont forest ecosystems and forest cover. Vermont is the third most forested state of the lower 48, with over 4.6 million acres of forest.**
- **Climate change will cause alterations in forest-pest/pathogen dynamics, as warmer temperatures allow for invasive pests and pathogens to expand in numbers and distribution in Vermont's forests, and high carbon affects physiology of trees, herbivorous insects, and phytophagous pathogens.**
- **The loss of cold-tolerant boreal forests in Vermont will result in declines in birds that depend on this habitat type including Bicknell's thrush (*Catharus bicknelli*), a globally rare species vulnerable to extinction.**
- **Vermont's forests currently remove approximately 75,000 metric tons of carbon from the atmosphere per year, valued at 16 million dollars. The role of Vermont's forests in carbon uptake will continue to be of value and likely increase as pressure to reduce greenhouse gas emissions amplifies with climate change.**
- **Several other human-driven factors impacting Vermont forests including parcelization and fragmentation will interact with the effects of climate change, requiring managers to adopt an adaptive management approach.**

1. Introduction

Climate change is having both gradual and long-term effects, direct and indirect on forests (Figure 1), including changes to biodiversity, productivity, forest structure, and ecosystem services (U.S. Geological Survey 2009, VT Department of Forest, Parks & Recreation 2010). Forests provide multiple valuable resources, including ecological diversity, ecosystem services, and ecosystem resilience, many of which are hard to quantify and therefore protect. Direct effects of climate change on forests include increased water use and evaporation as a result of warmer winters and longer growing seasons. Increased water use will decrease soil moisture, contributing to dry spells during summer, and decreased forest productivity. This will result in increased susceptibility of trees to disease, invasive species infestations, and threaten silvicultural resources (Rustad et al. 2012). Vermont forests in particular are vulnerable to increasing infestations by invasive species and damage from more severe and frequent forest disturbances as a result of climate change. Habitat ranges of certain Vermont tree species are at risk as temperatures increase with the potential to be pushed northward by the end of the century.

Forests also play an important role in reducing climate change through capturing and storing carbon and providing bioenergy resources. U.S. forests currently absorb approximately 13% of all carbon dioxide emitted through fossil fuel burning (EPA 2012) and forestland resources in the U.S. have the potential to produce bioenergy from over 600 million acres of timberland and forestland combined (DOE 2011). The combination of climate change induced threats to forest resources and the value of forests in reducing future climate change increase the need for sustainable future management of our forest ecosystems.

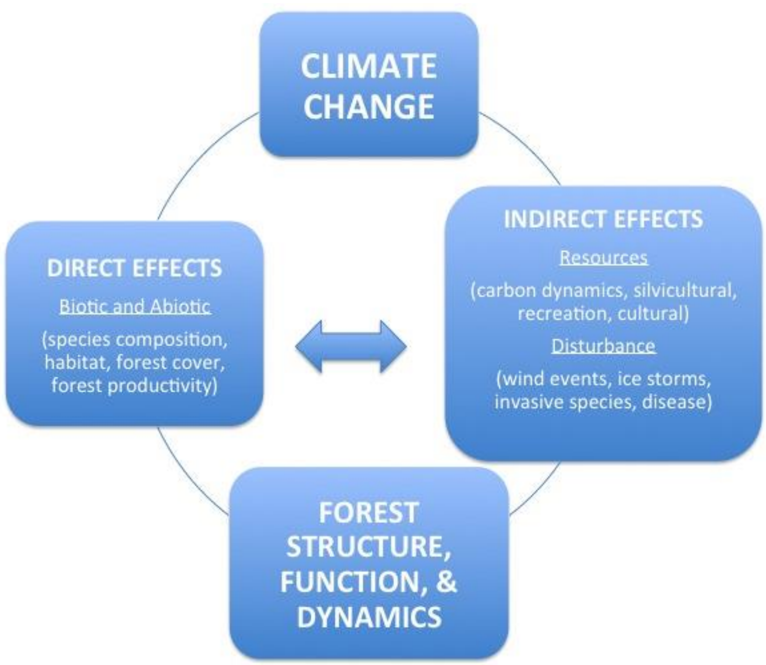


Figure 6.1 *Direct and indirect effects of climate change on forests. Adapted from Keeton et al. 2007*

1.1 Forest Structure

Forest ecosystems protect water quality, cycle nutrients, capture air pollutants, provide habitat, and help maintain biodiversity. They provide resilience again natural disturbances, climate variability, and invasive species. We depend on healthy forests to moderate temperature and reduce valley flooding, for tourism and economic resources, and for food and medicine (Vermont Monitoring Cooperative 2009). Humans have already altered most of the world's forests though our land-use history (Houghton 1994), only increasing the need to protect this invaluable resource as it continues to be altered by climate change.

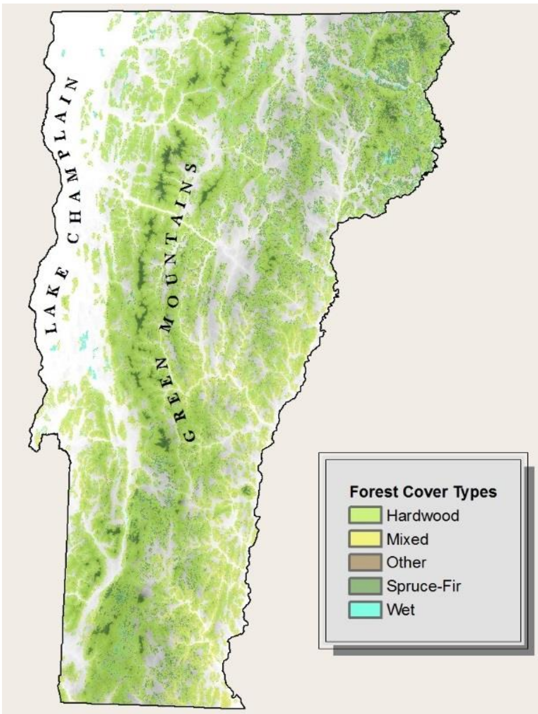


Figure 6.2 *Vermont Forest Cover Types. Map created by W. Seegers, UVM Spatial Analysis Lab, adapted from Vermont Forest Resources Plan (2010 (Vermont Department of Forests, Parks and Recreation 2010).*

1.2 Species Composition and Structure

Vermont's forests have not always been hardwood dominated as they are today. When glaciers receded 11,000 years ago, the first forests of Vermont were dominated by black spruce and paper birch. As the climate warmed, spruce and fir remained in higher elevations while lower elevations were dominated by eastern white pine, maple, birch, hemlock, beech, oak, and hickory, what has created the mosaic of mixed northern hardwood forests covering Vermont's landscape today (Wharton et al. 2003), (see Figure 6.1).

Widespread 19th-century clearing for agriculture shifted the majority of Vermont's forests from primary (never cleared) to secondary (regenerating) forests. Compared to primary forests, secondary forests are often less complex, younger in age, lack vertical and horizontal structure, and have fewer numbers of both live and dead trees (Keeton et al. 2007). This has direct effects on the ecological diversity of these ecosystems, especially their resilience to variability in climate and potential disturbances.

Approximately 78 percent, or 4.6 million acres, of Vermont is forested (Wharton et al. 2003), 86% of which is privately owned (Vermont Monitoring Cooperative 2009). Forest cover in Vermont plateaued and in 1997 began to decline slightly (Nowak et al. 2008). This trend may be attributable to forested land conversions and a combination of tree removals and tree mortality (VT Department of Forest, Parks & Recreation 2010). However, abandoned agricultural land, which is not accounted for in the forest inventory, but functions as wildlife corridors and riparian habitat, may offset this decline.

1.3 Projected changes to forest species habitat ranges, composition, and structure

Northeastern forests have been experiencing transitions in climate and species composition for tens of thousands of years. Forests are slow to respond to such variations, however, and it is therefore difficult to accurately model future forest species distributions as a result of climate change as humans accelerate the rate at which climate transitions are occurring. Trees have long life spans, slow dispersal rates and ability to adapt genetically to changing climate, adding to the complexity of modeling future suitable ranges based on such factors as increasing temperature

(Rustad et al. 2012). Human-accelerated climate change is making it even less clear how forests will respond to changes in suitable habitat. Increasing temperatures and changes in amounts of precipitation are already affecting Vermont forests.

1.4 Impacts to suitable habitat ranges

Climate models project dramatic range shifts of dominant tree species in the northeastern U.S. over the next 100 years (Rustad et al. 2012). High elevation spruce-fir forests in southern Vermont are most vulnerable to rising temperatures associated with climate change (TetraTech 2013), and climate models project their suitable habitat range to be virtually nonexistent in the northeast within 100 years (Rustad et al. 2012). Oak-pine forests, which are more tolerant to warmer temperatures, are projected to expand northward in Vermont and throughout the northeast, replacing current dominant hardwood species like maple and birch (Rustad et al. 2012, Wilmot 2011). However, species respond both individually and as a community, making it difficult to truly predict exactly how species will respond to the effects of climate change over time.

Temperatures have already seen a consistent warming trend in Vermont over the past 100 years. The average summer temperature has increased by 0.4 degrees Fahrenheit (0.22 degrees Celsius) per decade in Vermont, while winter temperatures have increased by 0.9 degrees Fahrenheit per decade over the past 100 years (0.5 degrees Celsius; National Weather Service 2013). Growing seasons have lengthened by an average of 3.7 days per decade, and are projected to increase (Betts 2011a, Betts 2011b, UCS 2006). These changes support model predictions toward a shift in growing zones north and downward in elevation, reducing suitable habitat for certain key Vermont species like red spruce and balsam fir, and allowing northern hardwood trees to survive at higher elevations. Spruce-fir forests are therefore most vulnerable to changes associated with climate change (Manomet 2009, Iverson et al. 2008, Woodall et al. 2009).

High elevation spruce-fir forests in Vermont are already experiencing changes in species distribution (Beckage et al. 2008). This study of forest composition on the western slopes of the Green Mountains indicates shifts in tree species range are already occurring. The boundary between the northern hardwood forest and boreal forest in this location has shifted upslope from 299 to 390 feet between 1964 and 2004 (Beckage et al. 2008). Although likely influenced by climate change, there are other compounding factors such as acid deposition and land use change that could also be affecting this forest range alteration.

According to multiple climate and vegetation models predicting habitat changes for common tree species across the Northeast, suitable habitat for 47 of 84 species is predicted to increase, decrease for 31 species, and remain unchanged for six species (Iverson et al. 2008). These models use data from the US Forest Service Forest Inventory Analysis models under low and high future emissions scenarios. Under both emissions scenarios, changes in suitable habitat are projected to significantly decrease for certain ecologically and economically important species such as sugar maple and balsam fir across the Northeast (Rustad et al. 2012). Some models project forests of the Northeast to shift from maple-birch forests to more southern adapted, oak-hickory forests, as shown by the map below (Figure 6.3).

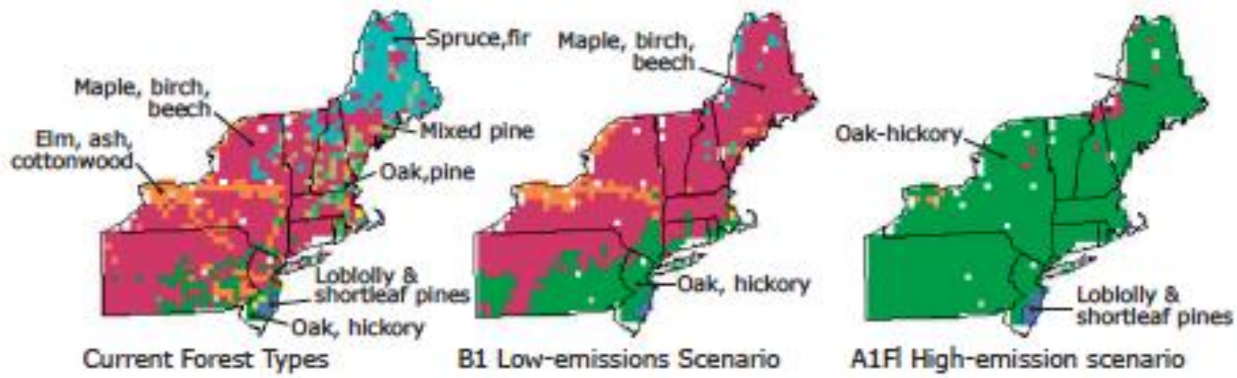


Figure 6.3 *Projected suitable habitat for forest type/tree species in New England under low and high emissions scenarios (Rustad et al. 2012)*

1.5 Impacts to species composition and structure

Climate change models project summer dry spells in Vermont to become more severe as temperatures increase. Warmer temperatures in the summer combined with less precipitation will increase stress on Vermont's forests. Sugar maple., a landmark Vermont species, has already experienced periods of significant decline during previous dry periods in Vermont and is especially at risk therefore to potentially amplified summer drought and heat stress (Vermont Monitoring Cooperative 2009). The Champlain Valley is warmer and drier than other parts of Vermont, making its ecosystems particularly vulnerable to heat stress and water limitations associated with climate change. It is likely that increased heat stress and water limitations will have an overall effect on forest health and productivity in Vermont (TetraTech 2013).

It is difficult to predict how forest structure will truly shift in response to climate change, as species are able to evolve and adapt over time both individualistically and communally in response to the effects of climate change. In Vermont, research has already shown changes in high-elevation species compositions over the past few decades. Vegetation surveys completed between 1964 and 2006 on Camel's Hump in Vermont have found evidence of species elevation distributions and composition shifts in response to an increase of 0.49 degrees F warming per decade (Pucko et al. 2011). Species responses to warming temperatures in this study were complex and individualistic at some elevations while at others species responded in communities. Overall, most species experienced a decline in population abundance over the survey period with the greatest amount of species compositional change experienced at the higher elevations. Samples were taken of the lower elevation, northern hardwood forests (maple, beech, birch) and high elevation spruce-fir forest. Although there were varying response levels to species shifts (both individual and group) in this study, it did prove that species are already responding to a minimal amount of climate change-induced warming temperatures in Vermont. The changes observed on Camel's Hump in overstory and understory vegetation were from less than two degrees of annual mean temperature increase (Pucko et al. 2011). Even with maximum emissions reductions, climate models predict a minimum temperature increase much more than we have already experienced by the end of the century. It is likely species shifts will remain constant or accelerate over the next century, and communities will become more divergent in their responses to the amplified effects of climate change (Pucko et al. 2011). This will make it more difficult to predict how species will respond in range and distribution, especially locally, to climate change.

The table below (Table 6.1) indicates tree species decline related to climate factors for key species across the Northeast. Species listed have been experiencing decline for multiple decades, likely augmented by climate change-induced factors. Other species of concern in Vermont in particular are sugar maple and eastern hemlock. Sugar maples are a landmark tree to Vermont's forest ecosystem both culturally and ecologically, and hemlock trees provide important habitat and biodiversity niches in our northern forest ecosystems. The boxes following Table 1 and later in this chapter provides more detail associated with threats these two species face from climate change related factors.

Table 6.1 *Tree Decline and Associated Climate Factors; adapted from Rustad et al. 2012*

Species/ Group	History	Role of Climate	Other Factors	References
Sugar maple	Periods of decline throughout Northeast and VT since 1912 – in VT periods of decline in 1991 and 2001 directly coincide with dry periods and pest outbreaks)	Susceptible to stress from increased dry spells and associated invasive species outbreaks; prolonged thaw-freeze events result in fine-root damage	Disease, loss of soil nutrients, disturbance, acid deposition	Vermont Monitoring Cooperative 2009 Millers et al. 1989 Bertrand et al. 1994 Decker et al. 2003 Fitzhugh et al. 2003
American beech	Widespread decline from beech bark disease (BBD) in the northeast since 1932 especially Vermont, New York, and Maine (44% in Vermont and New York's Adirondack Mountains, and 50% in Maine)	Beech thicket understory dominance in BBD infested areas augmented by climate change-induced variables (disturbance, invasive species)	Disturbance events	USDA Forest Service 2005
Birch	Widespread decline in the northeast since 1944	Areas and periods of birch decline coincide with extended freeze-thaw cycles	Soil nutrient loss	Balch 1944 Bourque et al. 2005 Braathe 1995
Ash	Widespread dieback in the Northeast since 1920	Susceptible to stress from invasive species such as the Emerald Ash Borer (EAB) and dry spells; Vermont ash species threatened from imminent invasion by EAB	Phytoplasmal disease, Asian beetle, disturbance events	Millers et al. 1989 Poland and McCulough 2006

Red spruce	Widespread decline in the Northeast since 1960, increasing over the last few decades as a result of acid deposition	Susceptible to winter injury as a result of reduced cold tolerance – intensified through warmer winters and rapid freeze-thaw cycles	Acid deposition, disturbance events	Friedland et al. 1984 Johnson 1992 Schaberg and DeHayes 2000 Bourque et al. 2005
Oak	Periodic declines in the Northeast since the 1900s	Susceptible to drought environmental stresses and pest outbreaks	Acid deposition, disturbance	Wargo et al. 1983

Box 6.1 Vermont Sugar Maple (*Acer saccharum*)

The economic impact of maple syrup in Vermont is over $250 million annually. Many Vermonters worry about the maple industry in the face of climate change. Here are some of the facts on how climate change impacts our maple trees:

- Warmer temperatures combined with longer growing seasons results in earlier bud break, increasing the susceptibility of trees to pests and pathogens.
- There are already documented correlations between sugar maple die back and periods of drought and forest tent caterpillar outbreaks. These have the potential to increase with the likelihood of increasing dry spells due to climate change.
- Sugar maple leaf out dates are becoming earlier each season with warming temperatures, as indicated by the below figure. Leaf out dates could continue to move forward as temperatures continue to rise with climate change. Earlier leaf out and flower development increases sugar maples' susceptibility to pest outbreaks.
- Tree health, soil moisture, and temperature affect sap production – climate change threatens VT's maple sugar industry due to reduced sap flow days as a result of warmer temperatures and a decline in sugar maple health (Skinner et al. 2010).

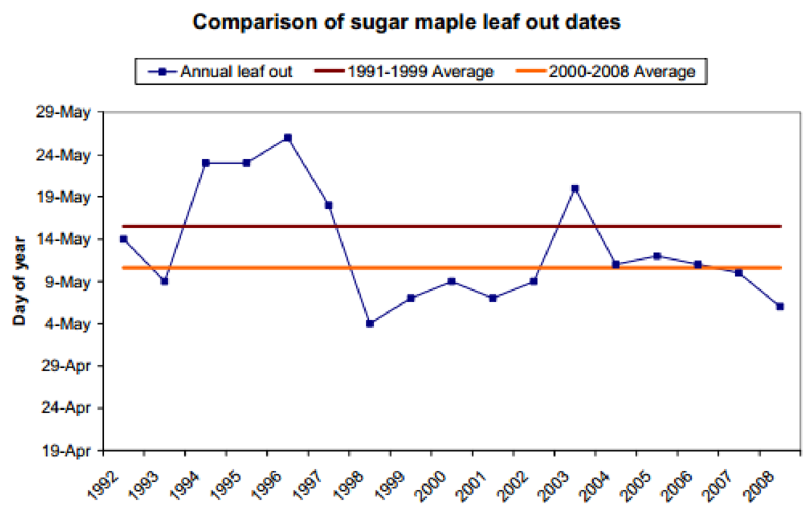


Figure 6.4 *Changes in sugar maple leaf out dates from Procter Maple Research Center, Vermont (Vermont Cooperative Monitoring Program 2009)*

2. Forest Productivity

Forest productivity is a measure of the net growth rate of a forest, or its net primary productivity (NPP). It is a combination of plant growth, reproductive success, biomass accumulation, phenology, and nutrient cycling. The amount of biomass (live and dead trees) added to a forest over time is a way to gauge its productivity, which is important because this affects the rate at which a forest produces timber and sequesters carbon (Rustad et al. 2012). Biomass accumulation increases when growth exceeds mortality in a forest.

A forest's soils are critical to forest health, providing nutrient cycling, physical support, habitat, and water quality protection. Soil texture, drainage, depth, and fertility are all important characteristics of forest health. Soils also play an important role in storing carbon through different levels of nutrient cycling (Vermont Monitoring Cooperative 2009).

2.1 Changes in forest productivity

Climate change's effects on growing season length and tree regeneration will affect forest biomass accumulation. Above ground live tree biomass has been decreasing on the east slope and the summit of Mount Mansfield since 1997 due to such stress events as the ice storm of 1998 and drought in 1999 (Vermont Monitoring Cooperative 2009). Stress from extreme weather events and changes increased and decreased moisture levels will continue to affect biomass levels in Vermont forests.

Changes in forest productivity on the small and large scale are unclear. Longer growing seasons and higher levels of atmospheric carbon dioxide could increase productivity, yet stresses imposed by water limitations, temperature and disturbance changes could decrease productivity (Rustad et al. 2012).

2.2 Impacts to tree regeneration

Tree regeneration in Vermont has the potential to be affected by changes in growing season due to climate change. Many tree species, like sugar maples and apple trees, depend on seasonal cold temperatures for regeneration. Earlier spring thaws and later frosts have already been damaging sugar maple buds and roots, affecting maple tree productivity, and also increasing apple tree susceptibility to certain pests (TetraTech 2013). (For more information on the effects of climate change on Vermont apple trees, refer to the Agriculture Chapter 7.)

Spring leaf-out is occurring earlier as a result of shorter winters. Research from northern hardwood forests at Hubbard Brook Experimental Forest in New Hampshire found significantly earlier spring leaf-out with an increase in green canopy of 10 days over a 47-year period (Richardson et al. 2006). Although extended growth periods should increase productivity, other stressors (water, heat, disease, pests, and acid deposition) often limit the extent to which forests are able to take advantage of longer growing seasons (Rustad et al. 2012).

Increased carbon dioxide levels (CO2 fertilization) and temperatures leading to longer growing seasons may increase tree growth rates initially which is often seen as a potential positive effect of climate change. However, despite CO2 fertilization, which improves water use efficiency, a longer growing season may result in increased rates of evapotranspiration, drying out soils leading to dry spells or short-term droughts. This will ultimately negatively affect tree growth through limited water availability (Wilmot 2011 and Huntington et al. 2009). Additionally, other factors associated with climate change that are also increasing (disturbance, invasive species) will continue to confound on the long term negative effects on tree growth.

Table 6.2 below describes some of the confounding factors that will work against the more immediate, positive effect of increased growth rates from elevated CO2 and longer growing seasons projected for forest ecosystems in the Northeast.

Table 6.2 *Confounding factors affecting forest productivity (Rustad et al. 2012).*

Confounding Factor	Effect
COMPETITION	Competition between species will increase as suitable habitat shifts (south to north) and some forest types replace others (high elevation softwood forests are replaced by hardwood forests in Vermont, for example).
NUISANCE SPECIES	Increased infestations by invasive species, pests, and pathogens; Hemlock woolly adelgid, pine blister rust, and emerald ash borer are already having major effects on forest productivity in the U.S. and Canada and seriously threaten Vermont's forests.
DROUGHT (DRY SPELLS)	Increased evapotranspiration will decrease soil moisture augmenting summer dry periods and associated plant stresses.
AIR POLLUTION	Potential increased amounts of air pollutants due to climate change can alter forest productivity and influence how trees respond to climate change; these include ground-level ozone, acids, and nitrogen compounds.
ACID DEPOSITION	Acid deposition, already an issue across the Northeast, may increase with increasing cloud cover and precipitation; this will affect high elevation forests (boreal spruce-fir forests in Vermont), many of which are already suffering from impaired nutrient availability and leaf damage as a result of acid deposition.

2.4 Impacts to soils and nutrient cycling

Increasing precipitation amounts in the winter could result in increased runoff from forest soils and also nutrient loss from within soils. The effects of changing temperature and precipitation amounts on other aspects of forest productivity such as nutrient cycles are still unknown (TetraTech 2013).

Box 6.2 Structural Complexity Enhancement (SCE) Forest Management

Disturbance-based forestry treatments that promote late-successional forest structure characteristics have beneficial effects on forest habitat, biomass retention, and structural diversity. An experimental silvicultural treatment in which structural complexity enhancement logging treatments were tested on Mount Mansfield and in Jericho through the Forest Ecosystem Management Demonstration Project (FEMDP) have proven to enhance forest structure when compared to conventional logging practices (Keeton 2006, Vermont Monitoring Cooperative 2009). These treatments provided merchantable timber while also retaining biomass, habitat, and carbon storage potentials.

Structure achieved through SCE silvicultural techniques (Keeton 2006):

- Vertical and horizontal heterogeneity
- Variation in tree size class and age distribution
- Increased levels of species diversity
- Recruitment of coarse woody debris
- Canopy gap formation

Disturbance-based logging practices which add structure to forest ecosystems while also generating revenue for landowners provide many opportunities for Vermont landowners in particular to sustainably manage their forests in the face of climate change.

3. Forest Disturbances

Ecological disturbance is an important factor in the diversity and complexity of forests globally. Forests are commonly impacted by biotic factors including pests and pathogens that attack trees and other plants, and abiotic factors such as severe weather-related events (flood, wind, freeze/thaw cycles, wildfire, etc.).

While Vermont forests will continue to be subject to disturbance, climate change is forecast to impact the long-term condition of Vermont forests by changing ecological disturbance frequencies and perhaps disturbance intensities. Beyond changes to individual disturbance vectors, climate change may lead to ecological change in situations where trees are already stressed by factors including unsustainably high tree densities, and the presence of pests and pathogens (Winnett 1998). The specific outcomes of interactions among biotic agents, abiotic interruptions and climate change are not clear (Anderson et al. 2004). However, abiotic factors such as temperature and moisture affect host susceptibility to pathogens and pathogen aggressiveness, changes in interactions between biotic diseases and abiotic stressors may represent the most substantial effect of climate change on plant diseases.

Although the impacts of individual disturbances such as forest pathogens on forest structure and function have been studied, there is little research on the interactions of climate and disturbance (Dale and others 2000). Thus, the extent to which climate change will affect the frequency, severity, or magnitude of disturbances is difficult to predict (Loehle and LeBlanc 1996). Research on impacts of climate change on plant pathogens has been limited, with most work concentrating on the effects of a single disturbance on the tree host, or the interaction of a single disturbance and climate. Disturbances may interact in a cumulative or cascading manner, with increases in one type of disturbance increasing the potential for other types of disturbances. (Kliejunas et al. 2009).

3.1 Biotic factors

Climate change will directly affect the extent and severity of forest disease- and pest- related tree mortality, depending on how the pathogen, the host, and the interaction between them change in response to novel climate patterns (Brasier 2005, Burdon et al. 2006). There exists a real potential for host tree species to become more susceptible to a pest or pathogen, or for climate change to lead to environmental conditions to become more suitable for the pest or pathogen, resulting in increased incidence of attack or disease (Kliejunas et al. 2009). Many pests and pathogens currently are limited by winter temperature, and seasonal increases in temperature are expected to be greatest during winter. Accordingly, both overwintering survival of pests and pathogens and disease severity are likely to increase.

Disease results from the interaction among a susceptible host, a virulent pathogen, and environmental conditions that support the pathogen. Determinants of forest response to insects and pathogens include characteristics (e.g. host specificity, aggressiveness, mode of attack) of the pest or pathogen, and the capacity of a forest to resist or recover from attack (Ayres and Lombardero 2000, Harrington 2002, Logan et al. 2003, Lovett et al. 2006).

Pests and pathogens, particularly species of fungi, may also be negatively impacted by climate change, as the host trees they depend on change in phenology, disease and pest resistance and range. For example, increased carbon dioxide concentrations resulting from climate change will coincide with lowered nutrient concentrations, greater accumulation of carbohydrates in leaves, and more plant defenses including waxes, protective cells and fibers (Chakraborty and others 1998). Two important effects of elevated carbon dioxide on host-pathogen interactions will be a delay in initial establishment of a pathogen and increased fecundity of pathogens (Coakley and others 1999). An increase in carbon dioxide may increase tree canopy size and density, resulting in a higher microclimate relative humidity, and a subsequent increase in foliar and rust diseases (Manning and Tiedemann 1995).

Box 6.3 Hemlock woolly adelgid

Increasing temperatures associated with climate change in Vermont will drive the abundance, timing of life cycles and physical characteristics of species, including forest pests and pathogens. Hemlock woolly adelgid (HWA; *Adelges tsugae*), a scale-like insect introduced from Japan, has attacked and caused widespread mortality of eastern hemlock trees (*Tsuga canadensis*) in North America. HWA siphons nutrients from live hemlock tree phloem, but also injects a toxic saliva that causes loss of foliage and decreased growth; attacked trees typically die six years after HWA infestation (McClure 1991). Originally introduced to Virginia in the 1950s, HWA has spread south to Georgia, and north to southern Maine, New Hampshire and Bennington and Windham Counties in Vermont (Paradis et al. 2007). The impacts of HWA infestation in New England are expected to be more severe than in the southern extent of the range, as hemlock is more abundant in the Northern Forest (Paradis et al. 2007). However, the colder winter temperatures of New England result in higher HWA mortality, and so slower population growth, relative to HWA at the southern extent of its North American range (Shields and Cheah 2004). As winter minimum temperatures increase with climate change, HWA populations will expand rapidly as this limitation abates. Ultimately, the loss of hemlock trees to HWA attack will have cascading negative impacts on New England ecosystems, including the increase of stream temperatures due to the loss of shading perennial foliage, the decline of wildlife species dependent on hemlock (e.g. Blackburnian warbler, *Setophaga fusca*, Rustad et al. 2012) and perennial cold water streams (salamanders, aquatic invertebrates; Ellison et al. 2005), higher rates of soil respiration and decomposition, a lack of plant-performed water filtering, and shifts in hemlock-associated plant communities (Paradis et al. 2007). Under the IPCC's most conservative climate change scenario maximum winter temperatures will reach 23 degrees Fahrenheit (-5 degrees Celsius); with this temperature change HWA will be established in the southern half of New England. Under the IPCC's highest carbon emissions scenarios, all of New England will be subject to HWA infestation (Paradis et al. 2007).

Figure 6.5 *Hemlock Woolly Adelgid (US Forest Service)*

3.2 Abiotic factors

Historically, large-scale abiotic disturbance events have been rare in the Northern Forest. However, when such disturbances do occur, windstorms including derechos, tornadoes, downbursts and icestorms are most frequently the cause. Typically these events result in high mortality of mature trees, canopy gaps, reductions in tree density and size structure, and changes in local habitat conditions at the stand level (Dale et al. 2001). Research suggests that these severe weather-related disturbances may be increasing in frequency as a consequence of climate change (Schelhaas et al. 2003).

Changes in climate including increased temperature, increased evapotranspiration, and extreme weather events may create unusually high levels of stress in forest stands (Columbia Mountains Institute of Applied Ecology 2005, Sturrock 2007). Forests already stressed by high tree density, pathogens, or atmospheric conditions may not survive the additional climatic stress (Winnett 1998).

The impact of these abiotic changes may be amplified as tree decline and mortality resulting from interactions between climate change and biotic factors weaken the resistance and resilience of forests. For example, stands where a high proportion of trees killed by insect outbreak are typically more susceptible to wildfire, given higher dry fuel loads (Bergeron and Leduc 1998, Hepting and Jemison 1958).

Box 6.4 December 2010 Windstorm

A severe, prolonged windstorm blew into western and central Vermont on December 1, 2010, during a period of heavy precipitation totaling as much as 2.36 inches of rain between November 30 and December 2, 2010 (Nash, Meteorologist-in-Charge, NOAA/National Weather Service-Burlington, VT, pers. comm. 2013). Sustained 20-35 mph winds from the southwest swelled in gusts over 50 mph in the Champlain Valley and hurricane force winds in excess of 73 mph raked across the Green Mountain ridge (Whittier 2010). Addison, Bennington, Chittenden, Franklin, Grand Isle, Lamoille, and Rutland Counties collectively suffered $3.5 million in property damage; fortunately no storm-related deaths or injuries were reported (NOAA Storm Event Database). In forests across Chittenden, Franklin and Lamoille counties patches of mature canopy as large as 20 hectares fell in the onslaught of wind. Forest managers were immediately faced with decisions regarding post-storm management without the benefit of information regarding likely outcomes. While stand-level disturbances (e.g. insect outbreak, wild fire) occur with some frequency and have been studied in the forests of western North America, such disturbances are relatively rare in the Northern Forest. As a result, there are few examples of management strategies following large-scale disturbances. Forest managers in Vermont elected to salvage harvest stands impacted by the 2010 windstorm to varying degrees. Given the likelihood that such storms will occur increasingly frequently in the Northern Forest as a result of climate change, researchers are currently quantifying ecological and economic outcomes of these management actions with the goal of informing future post-windstorm management.

4. Projected impacts to wildlife

As forest types in the Northeast shift in response to climate change, wildlife populations including mammals, birds, amphibians, and beneficial insects will be impacted at all scales from physiological function to geographic distribution; however, little research has documented or forecast changes in these groups resulting from climate change and habitat shifts (Rodenhouse et al. 2009). Across groups, climate change is likely to most severely impact species that have narrow habitat requirements, rely on habitat consisting of small, isolated blocks, are highly specialized to depend on small variety of plants, or are already declining or threatened

(Rodenhouse et al. 2009). Further research aimed at quantifying climate change impacts to northeastern fauna should focus on physiological and behavioral adaptations, food web dynamics, and impacts of interactions among climate change and other human-induced disturbances (e.g. development, timber harvest, acid deposition) (Rodenhouse et al. 2009).

In the Northeast, birds have received the most research attention aimed at quantifying consequences of climate change in fauna. Research suggests that some forest bird populations will shift northward and expand outside of their current range; as a result Vermont is likely to lose these species. Over the next 70 years, under the IPCC B2 scenario 15 bird species native to New Hampshire, New York, and Vermont will experience an average 91 percent decrease in suitable habitat in those states (Ralson and Kirchman 2013). Habitat for four species - three-toed woodpecker (*Picoides dorsalis*), black-backed woodpecker (*Picoides arcticus*), gray jay (*Perisoreus canadensis*), and ruby-crowned kinglet (*Regulus calendula*) - will become regionally extirpated (Ralson and Kirchman 2013). Bicknell's thrush (*Catharus bicknelli*), a rare migratory bird vulnerable to extinction (Lambert et al. 2008), is expected to decline by over 80 percent (Ralson and KIrchman 2013).

In addition to the loss of bird habitat area, aspects of habitat quality including vegetation composition and structure, food availability, predator abundance, and local weather will be affected by climate change (Rodenhouse et al. 2008). A study of black-throated blue warblers in New Hampshire suggests that climate change will reduce areas of high quality habitat at the bird's historic nesting altitude (1640-3000 feet above sea level) while extending poorer-quality habitat through higher elevations, resulting in a net lower average habitat quality across the bird's range (Sillett et al. 2000). These changes are likely to occur rapidly and will result in smaller populations by decreasing fecundity (Sillett et al. 2000).

5. Forest Resources and Management Opportunities

Vermont's forests serve as an extremely valuable economic and ecologic resource and are important to our natural and cultural well-being. Our forest products industry is estimated to generate over 1 billion dollars annually (VT Department of Forest, Parks & Recreation 2010). The Vermont forested landscape removes more than 75,000 metric tons of carbon from the atmosphere in a year, valued at $16 million dollars, in addition to providing valuable energy and tourism resources for the state (Vermont Monitoring Cooperative 2009).

Vermont forest managers will increasingly need to adapt their goals and actions as climate change impacts forest conditions. Managers may proactively reduce forest vulnerability by optimizing forest structure (densities of live and dead trees), changing the mosaic of management on a landscape scale, altering tree species composition, and limiting the potential for and impacts of severe disturbance by controlling invasive species and using controlled burns (Dale et al. 2001). When disturbances occur, managers may act to facilitate rapid forest recovery (by enhancing structural diversity, planting desirable species and limiting other environmental stressors (Dale et al. 2001). Finally, in order to develop realistic management goals and plans, forest managers will need to monitor conditions of forests both impacted and not impacted by disturbance, and to watch for interactions among disturbances (Dale et al. 2001).

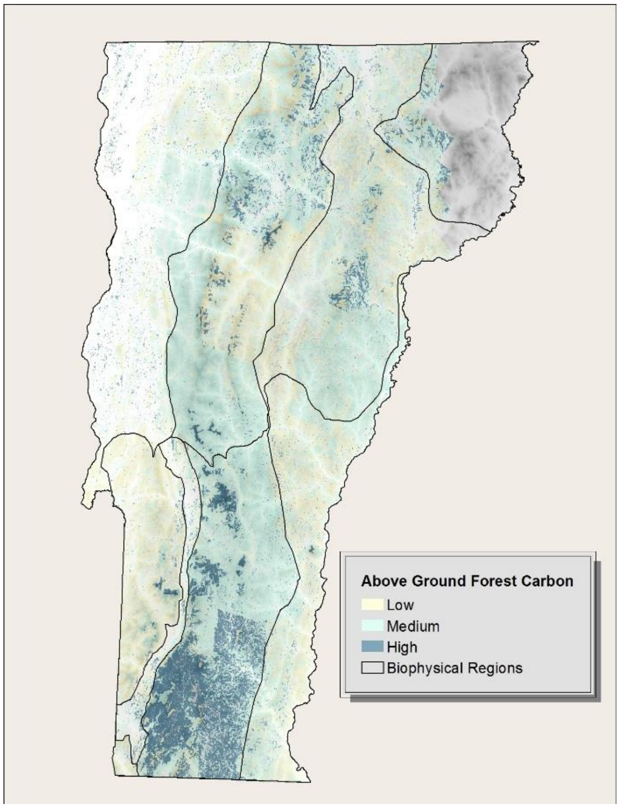


Figure 6.6 *Vermont Aboveground Forest Carbon (W. Seegers, UVM Spatial Analaysis Lab, Vermont* Northern Research Station 2008).

Strategies for mitigating and adapting to climate change impacts in Vermont forests will need to consider the array of human-caused disturbances and the interactions among disturbances. One example is increased parcelization, the division of large tracts of land into smaller ones, is a precursor of fragmentation, the loss of ecological continuity across the landscape as a result of residential and urban development (Haines et al. 2011).

Fragmentation of Vermont's forests threatens biodiversity and may impact the economics of forest management (Haines et al. 2011). In 2009 71 percent of Vermont's landscape was in parcels of 50 acres or larger; however, of those relatively large parcels only 24 percent were classified as forested without dwellings (Fidel et al. 2010). The number of forest parcels has been increasing by approximately 1,000 parcels a year since 1983, with the greatest increase in the smaller parcel size (1-9 acres) (USDA Forest Service Forest Inventory and Analysis,

5.1 Carbon storage and sequestration

Forests are extremely valuable in their ability to remove carbon dioxide from the atmosphere and also store carbon in biomass, soil, and wood products. In 2005, Vermont's forests almost entirely offset the state's greenhouse gas emissions (Vermont Forest Resource Plan 2010). In 2011, Vermont's emission levels were at 8.11 metric tons, surpassing 1990 levels. Although Vermont's emissions have declined about 10% since 2004, to continue to make a difference in emissions reductions, contiguous forest cover is needed in combination with renewable energy sources. Knowledge of areas with greater amounts of carbon storage, as indicated by the map below (Map 3), will help with management decisions when trying to determine how to protect or restore certain areas and help Vermont work toward some of its future emissions reductions and renewable energy goals. For more information on Vermont's commitment to renewable energy usage and emissions reductions, refer to the Energy and Policy Chapters.

Threats to forest cover, changes in species composition, and increased pests and pathogens due to climate change will all affect Vermont's forests' role in carbon storage. Map 3 shows forested areas of Vermont with the highest amounts of carbon storage. Many of these areas contain species highly vulnerable to climate change (spruce, fir, maple), and are already mapped as potential climate refugia (Figure 6.6).

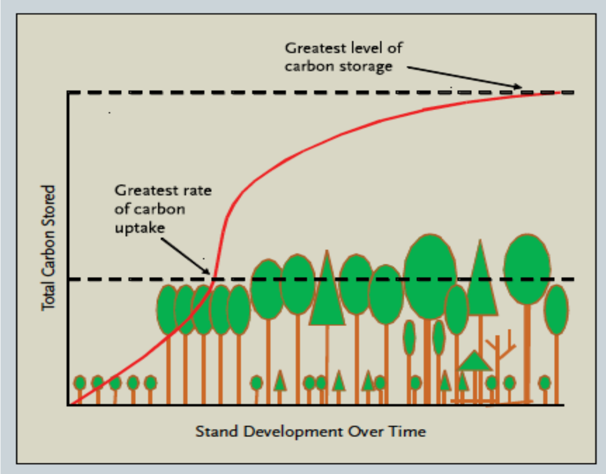
Although productivity of some species may initially increase with increased growing seasons, absorbing more carbon dioxide, multiple studies have shown that older, more stable forest ecosystems store maximum amounts of carbon (Nunery and Keeton 2010). When mortality and decomposition exceed net growth in a forest (when the forest is declining), forests release carbon dioxide. This is another potential issue imposed by climate change induced stresses – forests could turn into carbon sources instead of sinks. Some areas on Mount Mansfield may already be experiencing this as they suffer from mortality due to drought stress and decreasing biomass (Vermont Monitoring Cooperative 2009).

Vermont has declared that it will reduce its emissions to 50% of 1990 levels by 2028. To do this, the role of forests in carbon storage will need to be increased. It is therefore mandatory to protect forests with high carbon storage and to manage forests with low carbon for increased carbon sequestration and storage. The more we know about current carbon storage and release in Vermont forests, the better we are able to manage Vermont's carbon budget (Vermont Monitoring Cooperative 2009). The possibility of Vermont entering the carbon market is becoming more imminent as our need to find additional ways to offset and be accountable for greenhouse gas emissions. Domestic and international carbon markets are complex and difficult for a small state like Vermont with many private landowners to participate in, but this may change with time.

Box 6.5 Forest management for maximum carbon storage

Sustainable forest management practices are imperative for the future of our forests. Younger forests are sequestering or removing more carbon dioxide from the atmosphere than older forests because they have more new growth, but older forests have more wood material to store carbon and act as carbon sinks. What is the optimum forest management practice for maximum carbon uptake?

- Maintenance of structural complexity helps with resilience to climate change – this includes uneven-aged trees, canopy gaps, and trees of different sizes
- Passive forest management has proven to achieve the highest amounts of carbon storage (Nunery and Keeton 2010)
- Intensified regeneration cutting has proven to reduce net carbon storage (2010)
- Disturbance-based forestry practices which promote late-successional forest structure have proven to maintain biomass and carbon storage in northeastern forests (Keeton 2006)
- Younger, regenerating forests have the highest rates of atmospheric carbon uptake but forests at later stages in stand development have the highest amounts of overall carbon storage (Nunery and Keeton unpublished)



5.2 Bioenergy

Forest management activities produce biomass fuel sources (slash, chip material) that can help to offset greenhouse gas emissions (Vermont Monitoring Cooperative 2009). Bioenergy resources will become more intrinsic to Vermont and the United States as a means to reduce climate change following renewable energy commitments. Currently, four percent of Vermont's energy usage is from biomass sources, and Vermont is already recognized as a leader in biomass production. Multiple locations around Vermont and at varying scales use biomass generators, ranging from the McNeil Woodchip Plant in Burlington to Middlebury College to home boiler systems and pellet stoves. It may be challenging to balance bioenergy needs with maintaining intact forests for carbon sequestration.

6. Adaptation and Mitigation

Maintaining contiguous forest cover and reducing the conversion of forested land cover is one of the most effective ways to mitigate climate change (Vermont Monitoring Cooperative 2009). Vermont has multiple programs supporting the protection of privately owned forestland, including the Forest Legacy Program (FLP) and the Current Use Program (Use Value Appraisal Program). The FLP is a partnership with the US Forest Service that protects privately owned forestlands from conversion to non-forest uses. The Current Use Program provides landowners with tax incentives to sustainably manage the forest on their property while also agreeing to not develop the land. This program has been Vermont's most successful forestry and conservation program, maintaining large amounts of forested lands across the state (VT Department of Forest, Parks & Recreation 2010).

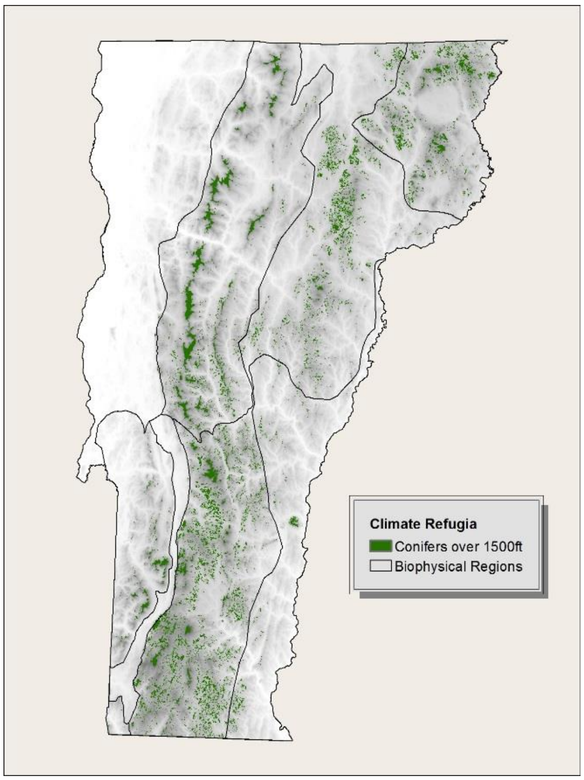


Figure 6.6 *Vermont spruce-fir forest, potential climate refugia (W. Seegers, UVM Spatial Analysis Lab, VT Department of Forests, Parks & Recreation)*

Maintaining a healthy and diverse forest is also one of the best ways to adapt to the effects of climate change and related disturbances. A variety of tree sizes, ages, and distributions will make a forest more resilient to disturbance and changes in temperature and moisture. As the suitable range of certain species is projected to change, scientists have started mapping locations that might serve as refugia to assist with management strategies. The spruce-fir forest ecosystem in Vermont is one that is currently being focused on, as its habitat is under the greatest threat from climate change, as discussed previously. Map 4 shows areas that offer potential refugia for Vermont's spruce-fir forests.

Long-term monitoring and research into sustainable forest management approaches are mandatory for forest productivity to adapt to the effects of climate change. Maintaining structural complexity in our forests will help them adapt to future changes brought about by climate change.

7. Summary Table Rating Quality of Information

Key Message 1	Increased temperatures will lengthen growing seasons and increase suitable range for certain Vermont tree species like oak and white pine, but decrease suitable range for cold-tolerant species like red spruce and balsam fir. Models project that by the end of the century, an oak-hickory forest could dominate the Northeast with spruce-fir forests being virtually non-existent, and maple-beech-birch forests may persist only in Maine. Evidence Base: Rustad et al. 2012; Beckage et al. 2013; Betts 2011; Pucko et al. 2011; Wilmot 2011 Assessment of Confidence Based on Evidence: **Medium**
Key Message 2	Alterations in precipitation cycles (wetter winters and extended dry spells in late summer/fall) will place more stress on important tree species such as sugar maple and red spruce, which have already experienced periods of decline in Vermont. Warmer temperatures will result in earlier bud burst and flowering periods for certain species, making them more susceptible to pests and pathogens. Evidence Base: Vermont Monitoring Cooperative 2009; TetraTech 2013; Rustad et al. 2012; Mohan 2009; Wilmot 2011 Assessment of Confidence Based on Evidence: **High**
Key Message 3	Increases in frequency of natural disturbances as a result of climate change will affect Vermont forest ecosystems and forest cover. Vermont is the third most forested state of the lower 48, with over 4.6 million acres of forest. Evidence Base: Dale et al. 2001, Schelhaas et al. 2003 Assessment of Confidence Based on Evidence: **Medium**
Key Message 4	Climate change will cause alterations in forest-pest/pathogen dynamics, as warmer temperatures allow for invasive pests and pathogens to expand in numbers and distribution in Vermont's forests, and high carbon affects physiology of trees, herbivorous insects, and phytophagous pathogens. Evidence Base: Brasier 2005, Burdon et al. 2006, Kliejunas et al. 2009, Paradis et al. 2007 Assessment of Confidence Based on Evidence: **High**
Key Message 5	The loss of cold-tolerant boreal forests in Vermont will result in declines in birds including Bicknell's thrush (*Catharus bicknelli*), birds that depend on this habitat type.

	Evidence Base: Lambert et al. 2008, Ralson and Kirchman 2013, Rodenhouse et al. 2008, Rodenhouse et al. 2009, Sillett et al. 2000 Assessment of Confidence Based on Evidence: **High**
Key Message 6	Vermont's forests currently remove approximately 75,000 metric tons of carbon from the atmosphere per year, valued at 16 million dollars. The role of Vermont's forests in carbon uptake will continue to be of value and potentially increase as pressure to reduce greenhouse gas emissions increases with climate change. Evidence Base: VT Department of Forest, Parks & Recreation 2010; Nunery and Keeton 2010; Vermont Comprehensive Energy Plan 2011 Assessment of Confidence Based on Evidence: **Very High**
Key Message 7	Several other human-driven factors impacting Vermont forests including parcelization and fragmentation will interact with the effects of climate change, requiring managers to adopt an adaptive management approach. Evidence Base: Fidel et al. 2010, Haines et al. 2011, USDA Forest Service Forest Inventory and Analysis, Northern Research Station 2008 Assessment of Confidence Based on Evidence: **Very High**

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Chapter 7: Agriculture and Food Systems

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Key Messages

- **Climate change is altering the Vermont growing season. Climate change models project that Vermont's frost-free period will extend by as much as one month by the end of the century. This extended growing season can increase overall crop productivity and create new crop opportunities such as grapes and peaches. This warming could have a negative impact on agricultural shrubs and fruit trees, such as apple, that need a prolonged winter chilling period into order to initiate the flowering process in the spring.**
- **Climate change models also project greater variations in seasonal temperature and precipitation. Spring time fluctuations could lead to reduced fruit size or frost damage. In addition, excessive soil moisture levels could result in delayed spring planting. During the summer, climate models project more short- and medium-term dry periods for the region. Increased summer dry spells will be occurring at a time when crop water requirements are also increasing due to warmer temperatures.**
- **Changes in atmospheric carbon dioxide and tropospheric ozone will also impact Vermont's agriculture. Enhanced atmospheric CO2 promotes photosynthesis, potentially fueling the growth of many Vermont plant varietals. On the other hand, tropospheric ozone is projected to adversely affect the productivity of agricultural crops in Vermont.**
- **For Vermont livestock operations, summer heat stress could lead to decreases in livestock productivity, but most pronounced operational impacts arise from increased feed and energy costs. Climate change impacts on these indirect costs make the industry vulnerable.**
- **The projected higher incidence of extreme weather events can create floods that degrade and inundate farms and livestock operations. If the flooding occurs during the growing season, crops can be lost due to diseases and soil compaction. In addition, extreme weather events can result in damage to planting beds, furrows, ditches, and other agriculture-related infrastructure.**
- **Given the upcoming climate changes, it is essential that Vermont agriculture enterprises develop forward-looking adaptation plans. Farm production programs that address climate change include changing operational timing, investigating new crops and new varietals, increasing cover crop and minimal tillage practices, landscape level farm planning and increasing farm energy efficiency. Some Vermont agricultural endeavors will adapt to climate change more easily depending on farm production practices and location. The overall impact on Vermont livestock and crops will depend on the collective rate of adaptation.**

- **Many greenhouse gas emissions stem from agricultural management choices so agricultural producers can play an active role in greenhouse gas mitigation. Common mitigation areas include improving carbon sequestration in biomass and soils, decreasing fuel/ fertilizer inputs, and reducing methane emissions from livestock production.**
- **When developing agricultural adaptation and mitigations policies, it is essential to include small to medium sized agricultural enterprises in planning. Small agricultural businesses are particularly vulnerable to climate change due to the physical concentration of assets and limited overall financial resources.**

1. Vermont State Agriculture Background

Agriculture has always played an important economic and social role in Vermont. Often associated with cows and green rolling hills (Figure 7.1), Vermont has over two-thirds of its population living in areas designated as rural. The agricultural sector employs over 10,500 Vermonters (Dunnington, 2010) and, in 2012, produced close to $700 million in cash receipts (Table 7.1) (United States Department of Agriculture (USDA), Economic Research Service, 2012). Vermont's major agricultural commodities include dairy products, beef, maple syrup, apples, and assorted vegetables. Vermont's agricultural sector plays an important role in providing foods that are fresh, high-quality, and local (Wolfe et al., 2008).

Vermont Agriculture
2012 Cash Receipts
in 000s

Dairy Products	$ 500,584
Cattle and calves	69,935
Maple products	26,625
Vegetables	13,480
Feed crops	13,340
Apples	8,824
All other	66,525
	$ 699,313

Table 7.1: *Vermont Agriculture Cash Receipts by Commodity (USDA, Economic Research Service 2012).*

Figure 7.1 *Holstein Heifer (Wikipedia Commons)*

2. Overview of Climate Change Elements Influencing Vermont State Agriculture

Climate change is altering the Vermont agricultural landscape. Over the next century, climate change models project that Vermont will experience warmer temperatures, variations in seasonal precipitation, increased frequency of weather events, and elevated levels of atmospheric carbon dioxide and tropospheric ozone.

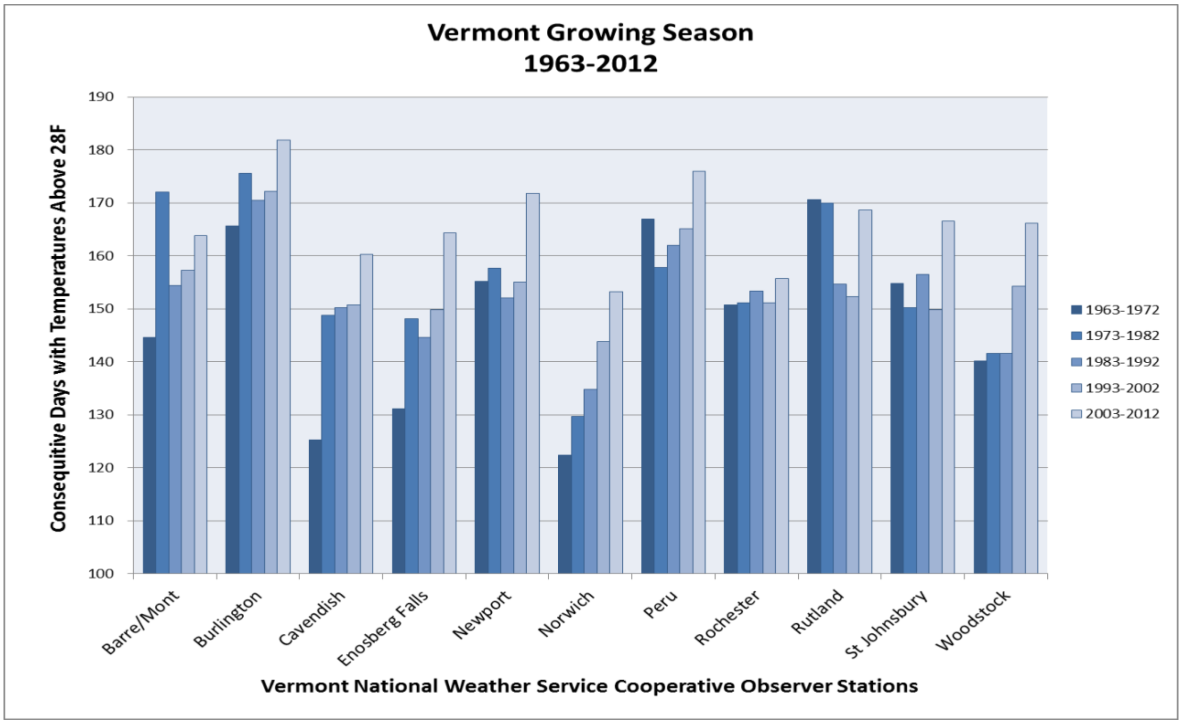

Figure 7.2 *Historical Vermont Growing Season at 11 Cooperative Stations in Vermont. The growing season is classified as the length of time between the last spring freeze and the first autumn hard freeze (daily minimum temperature drops below 28F). The graph shows the frost free day average across five decades. In cooperation with the Burlington National Weather Service office, stations were selected based on the length and quality of observation data, taking into account changes in instrumentation and relocation of observation stations.*

2.1 Warmer Temperatures

Climate change has already increased the growing season by 3.7 days per decade. The growing season is classified as the length of time between the last spring hard freeze and the first autumn hard freeze (daily minimum temperature drops below 28F). The increase in Vermont's growing season is visible in Figure 7.2. Future climate projections indicate a continuation of this trend, with warmer seasonal temperatures resulting in later first autumn frost date and earlier last-spring frost date. This frost-free period extends the growing season by as much as one month by the end of the century (Hayhoe et al., 2007).

2.2 Enhanced Atmospheric Carbon Dioxide

Atmospheric concentrations of carbon dioxide have been steadily rising, from approximately 300 ppm (parts per million) in 1900 to the current atmospheric level of approximately 400 ppm. Research indicates that increasing carbon dioxide modifies the productivity and water fluxes of vegetation. Crop productivity generally responds positively to increased atmospheric CO2 concentration, but the response depends on the species and local specific environmental conditions. Productivity of many plant varietals may be positively affected by the increases in atmospheric carbon dioxide. (McGrath & Lobell, 2013; Twine et al., 2013)

2.3 Elevated Tropospheric Ozone

Surface level (tropospheric) ozone is formed when volatile organic compounds, nitrogen oxides and carbon monoxide react with oxygen. These pollutants bake together when high temperature is combined with high solar radiation. Exposure to ozone causes visible and physiological damage to plants. Ozone's effect on vegetation has been examined in controlled greenhouses, open topped chambers, and field crops. These studies have demonstrated that exposure to ozone reduces plant photosynthesis and growth (Felzer, Cronin, Reilly, Melillo, & Wang, 2007). The various research studies designed to evaluate elevated ozone suggests productivity declines in the range of 5% to 15% among sensitive plants (Booker et al., 2009). It must be noted though that there is considerable genetic variability in plant responses to ozone (Felzer et al., 2007).

2.4 Increased Frequency of Extreme Weather Events

Under all climate change scenarios, extreme precipitation events are expected to occur more frequently (Betts, 2011). These extreme precipitation events can negatively impact production levels by harming growing crops and degrading top soil through erosion. In addition, repeated flooding damages food transportation networks and food system infrastructure located in close proximity to rivers and lakeshores (Dunnington, 2010).

2.5 Variance in Patterns and Amounts of Seasonal Precipitation

Climate change models project overall wetter conditions in the Northeast with total precipitation projected to increase in the spring and winter (Betts, 2011). The rising temperature is expected to result in more frequent short-term water scarcity by the end of the century.

3. Vermont Agriculture Crop Impacts

Impending climate changes have the potential to both positively and negatively affect the patterns and productivity of Vermont State crops.

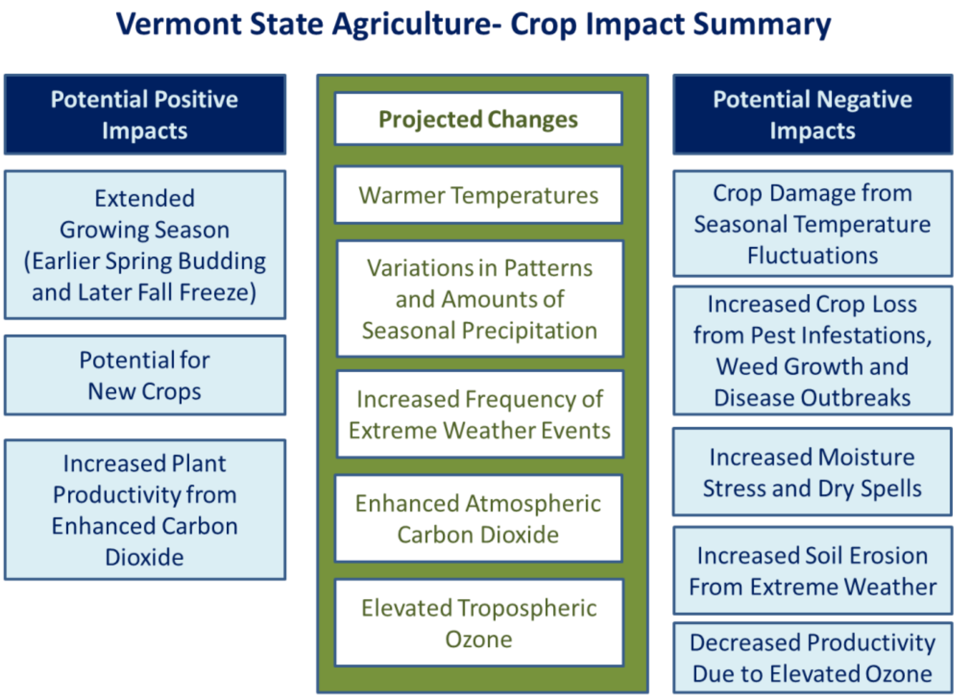

Figure 7.3 Vermont State Agriculture- Crop Impact Summary. The illustration shows projected climate changes positive and negative impacts on Vermont specific agriculture.

3.1 Extended Growing Season and Potential for New Crops

Continuing recent trends (See Figure 7.2), even under low emission scenarios, climate change models predict that the growing season will be extended by one month by the end of the century (Hayhoe et al., 2007). Observations by Ray Allan of Allanholm Farm in South Hero, Vermont, so that apple trees are blooming a full week earlier, on average, than they were when he became

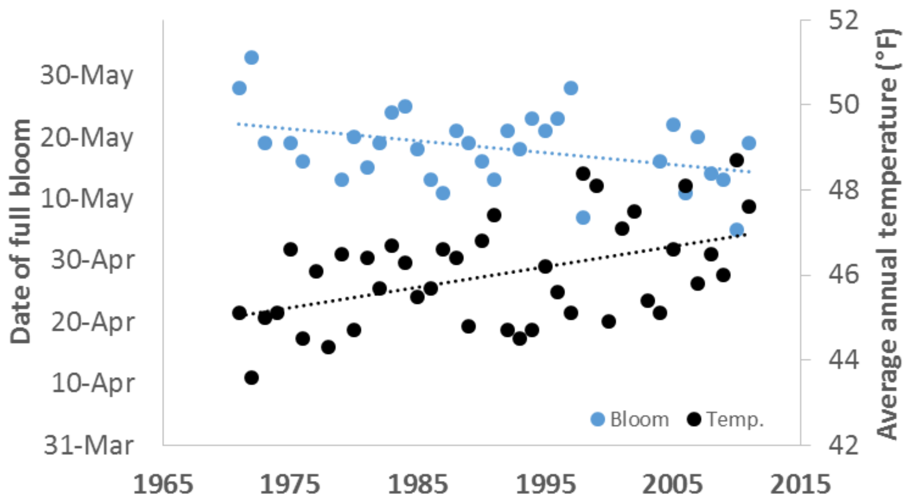

Figure 7.3 *MacIntosh Apple Trees—Date of full bloom at Allanholm Farm, South Hero , Vermont. Climate data is also collected at Allanholm Farm as part of the NWS cooperative observer program. The plot highlights the trend of early blooms over the forty year time frame from 1971 to 2011. Data courtesy of Allenholm Farms and NOAA/NWS.*

proprietor of the farm in 1971. Mr. Allan is also a cooperative observer for the National Weather Service. Warming temperatures can be viewed as an opportunity for crops that require a relatively long growing season such as watermelon, tomatoes, peppers, peaches, and European red wine grape varieties (Wolfe et al., 2008). To capitalize on these opportunities, organizations need to have enough capital to take risks on new crops and develop a market for the new crops (Wolfe et al., 2008).

3.2 **Increased Plant Productivity from Enhanced Carbon Dioxide**

Higher CO2 in atmosphere promotes photosynthesis potentially leading to increased yields in plants (McGrath & Lobell, 2013). Many plants in the Northeast United States are considered part of the C3 photosynthetic pathway. These C3 varieties can demonstrate productivity increases of 20% to 30% when grown at twice current CO2 levels in optimal conditions. These optimal conditions require more fertilizer, ideal temperatures, unrestricted root growth, and control of weeds, insects, and disease (Wolfe et al., 2008). Pasture forage species may experience accelerated metabolism and advanced development with rising temperature, but soil conditions and water availability will constrain carbon dioxides production impacts (Izaurralde, Thomson, Fay, & Morgan, 2011).

3.3 **Crop Damage from Seasonal Temperature Fluctuations**

Vermont climate projections indicate increased spring and fall temperature fluctuations. Warmer temperatures during the reproductive period could reduce fruit or grain size because the rapid rate of development and increased respiration rates (Hatfield et al., 2011). In addition, warm early spring temperatures can lead to early bud-burst or bloom of perennial plants resulting in frost damage with the return of cold winter temperatures (Wolfe et al., 2008)

Some crops in Vermont require exposure to a prolonged winter chilling period into order to initiate the flowering process in the spring. Agricultural shrubs, fruit trees, and winter grain cereals are some of these agricultural crops requiring this winter chilling period. This ensures that reproductive development occurs in the spring and summer rather than autumn. If these chilling requirements are not fulfilled, plant yields will be affected (Wolfe et al., 2008). Some perennial plants, such as apples and blueberries, require 1,000 hours below 45°F to produce profitable yields (Dunnington, 2010). Under some climate scenarios, southern Vermont winters may not meet these vernalization requirements.

3.4 **Increased Moisture Stress and Dry Spells**

Vermont horticultural crops (such as melons, sweet corn and tomatoes) are more sensitive than field crops to short-term environmental stresses that affect reproduction, water content, appearance, and flavor quality (Jackson et al., 2011). In addition, excessive soil moisture levels, specifically in the spring, can result in farmers delaying their spring planting. This can have a significant economic consequence since farmers receive a premium for early spring production of horticultural crops such as melon sweet corn and tomatoes (Wolfe et al., 2008).

Although regional climate models indicate more overall precipitation, the rainfall will be concentrated into more extreme precipitation events and skewed towards the winter months. During the summer, climate models project more short- and medium-term dry periods for the region (Wolfe et al., 2008). Increased summer dry spells will be occurring at a time when crop water requirements are also increasing due to warmer temperatures. For some plants, even short dry periods during critical growth and reproduction stages can have profound effects on plant productivity and reproduction (Hayhoe et al., 2007). The relative impact of these dry spells depends on irrigation systems and competing water demands. Grain and silage crops may not bring sufficient profit to warrant investment in irrigation equipment and thus are particularly vulnerable to dry spells. High value horticultural crops may warrant irrigation equipment (McDonald & Girvetz, 2013; Wolfe et al., 2008). Irrigation is covered more fully in the adaptation section.

3.5 **Increased Crop Loss from Pests, Weeds and Disease Outbreaks**

In the realm of weeds, diseases and pests, there will be emergent surprises resulting from departures from current ecological systems. Some Vermont agricultural crops will experience declines in crop production due to increased stress from weed growth, disease outbreaks, and pest infestations.

In Vermont, the range of agricultural diseases may expand under changing climate by impacting the host, crop plant, and the pathogen. Host plants may become more susceptible to diseases when they are pushed to the limits of their temperature range and certain pathogens have increased growth rates at higher temperature. Under conditions of climate warming, temperate climate zones (those with cold seasons) are likely to experience longer periods of temperatures suitable for pathogen growth and reproduction. The increased frequency of extreme precipitation events could enhance crop disease risks that need moisture to proliferate, such as potato and tomato blights (caused by Phytophthora infestans) or apple scab which effects apple quality (Petzoldt & Seaman, 2006).

Although less is known regarding climate change and invasive weeds, the completed studies highlight concerns. Research indicates that some fast growing weed species are especially adapted to utilizing extra carbon dioxide due to differences in the photosynthetic system (Ziska, 2007). Weed species have a greater genetic diversity than most crops. This improves their ability to adapt to upcoming climate variations (Wolfe et al., 2008). Additionally, the range of certain weed species is expanding with increasing temperatures, allowing them to further adapt to new habitat areas (Ziska, 2007).

Warmer temperatures and variations in precipitation will increase pest populations with negative productivity implications. Increased temperatures can potentially increase insect population size, expand insect geographic ranges, and result in higher insect overwintering success. In Vermont, pests such as the flea beetle could become more abundant if milder winters encourage their survival. Most research suggests that Vermont farmers will have more types and higher numbers of insects to manage (Petzoldt & Seaman, 2006).

Figure 7.4 *Flooded Corn Field, Plank Road in New Haven, Vermont October 2010*

3.6 **Increased Soil Erosion and Crop Damage from Extreme Weather**

Extreme precipitation can create floods that can harm crops and degrade the top soil. Field flooding during the growing season has a multitude of negative consequences. If the flooding occurs during the growing season, crops can be lost due to anoxia or root diseases. If heavy farm equipment is used on the fields during saturation, the soil is compacted (Wolfe et al., 2008.) Extreme weather events can result in damage to planting beds, furrows, ditches, and other agriculture-related infrastructure (Jackson et al., 2011).

3.7 Decreased Productivity Due to Elevated Ozone

Elevated tropospheric ozone is projected to adversely affect the productivity of agricultural crops and tree biomass in Vermont. Studies focused on ozone have demonstrated reduced photosynthesis, growth, and other plant functions (Felzer et al., 2007). The magnitude of ozone damage varies greatly with crop species and the research community agrees that more specific-varietal research is desirable. Recent research shows that ozone sensitive plants include livestock forage (such as alfalfa and clover), fruit bushes, grapes, lettuce, potato, spinach, tomato, and watermelon. In addition to production reductions, studies suggest that elevated tropospheric ozone impacts product quality. Potato plants grown in elevated ozone had lower sugar concentration and higher ascorbic acid (Booker et al., 2009). Although additional research is needed, elevated tropospheric ozone presents a risk to productivity of agricultural crops and tree biomass in Vermont.

4. Vermont Livestock Impacts

Vermont's livestock industry is the backbone of state agriculture, contribute almost 85 percent of total Vermont's agricultural cash receipts (United States Department of Agriculture (USDA), Economic Research Service, 2012). The projected variations in temperatures, seasonal precipitation, and weather events will impact the productivity of this sector.

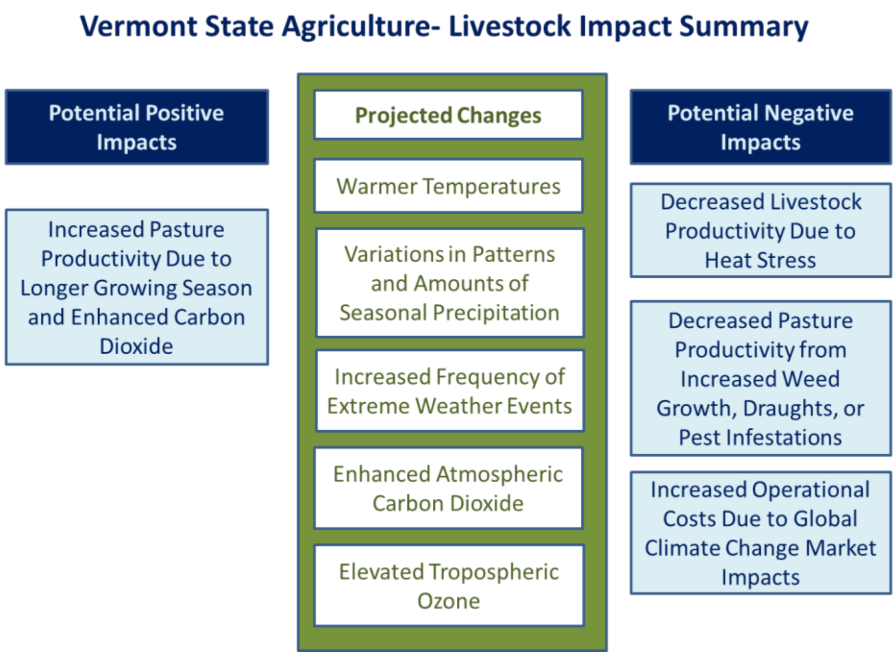

Figure 7.5 Vermont State Agriculture- Livestock Impact Summary. The illustration shows projected climate change positive and negative impacts on Vermont specific agriculture.

4.1 **Pasture Productivity**

Many of the agricultural crop implications described earlier in this section directly affect cow and cattle operations through pasture productivity on home grown forage. The warmer temperatures (extended growing season) and enhanced atmospheric carbon dioxide are anticipated to increase field productivity (Hayhoe et al., 2007). Increased weed growth, pest infestations, and seasonal draughts are anticipated to decrease field productivity (Petzoldt & Seaman, 2006; Ziska, 2007). Regarding carbon dioxide effects, the pasture species response is consistent with the general responses of other vegetation including accelerated metabolism and advanced development. Similarly, soil resources and moisture availability will often constrain direct carbon dioxide effects (Izaurralde et al., 2011; Wheeler & Reynolds, 2013).

4.2 **Livestock Productivity from Heat Stress**

Climate change induced warmer temperatures is projected to increase the number of extremely hot days in summer. These extremely hot days (maximum temperatures greater than 90°F) have an effect on dairy productivity and herd health. Cows are panting animals. So when cows are hot, they pant instead of eating which cuts their overall calorie intake. This in turn reduces milk yields and slows weight gain in dairy cows. In addition, heat stress lowers the reproductive efficiency in the herd due to the reduction in cow conception. Without a calf, the dairy cow will not produce milk. In addition to lower milk production, heat stress can increase herd vulnerability to disease. Many livestock operating factors influence the severity of this heat stress including air velocity, radiation, animal density, and animal insulation (Berman, 2005; Chase, 2006).

4.3 Livestock Operating Costs

Dairy and cattle operations profitability is related to their overall operating costs including feed costs and energy costs. Vermont feed costs are not isolated from the global feed and fodder supply chain. Given global climate change dynamics, economic researchers anticipate substantial risks to the volume and quality of U.S. animal feed supply chains which could potentially drive up prices (Wheeler & Reynolds, 2013). In Vermont, the potential upside from increased growing season could be more than offset by the increased price of off farm livestock feed. Climate change effects on overall energy prices are comprehensively covered in the Energy Section of this report. [See Chapter 4: Energy] These indirect costs of energy and feed make the Vermont dairy industry vulnerable to climate change.

- **Box 7.1 Climate Change, Extreme Weather, and Small Business Vulnerability**

Small businesses are particularly vulnerable to climate change due to their physical concentration of assets and limited overall financial resources.

In contrast to the greater geographic diversification of larger companies, many small businesses have concentrated consumer markets and physical assets. A single extreme weather event in their location can cripple a small business. The Insurance Institute for Business and Home Safety estimates that one in four businesses do not reopen following a major disaster. (Reynolds, 2013)

In addition, many small enterprises face pressure on the management of their limited financial resources. Climate change increases the year to year variation in temperature and precipitation which can reduce the predictability of many agricultural based businesses. With limited resource reserves, this yearly boom-and-bust cycling increases small business risk and overall vulnerability.

5. Agricultural Resilience

As summarized in sections one through four, climate change will have significant impacts on Vermont agriculture. In light of these changes, this report focuses on both adaptation and mitigation elements under the umbrella of resiliency.

Some Vermont agricultural endeavors will adapt to climate change more easily than to others. The rate of adaptation will depend on type of farm production and specific farm location. The overall impact on Vermont livestock and crops will depend on the collective rate of mitigation and adaptation.

Many greenhouse gas emissions stem from agricultural management choices, so agricultural producers can play an active role in decreasing emissions. Some of the most common areas discussed include carbon sequestration in biomass and soils, decreasing fuel, fertilizers, and pesticides input and reducing methane emissions from livestock production (Grubinger, 2011).

6. Farm Production Practices

Some farm production programs that address climate change are simply good management practices such as: efficient nitrogen fertilizer and manure use, farm energy efficiency, and cover cropping. Innovative farming practices, such as use of alternative fuels and on-farm energy generation, may address climate change and enhance profitability (Grubinger, 2011).

6.1 Farm Operation Timing.

A central component to successful agricultural adaptation in Vermont is evaluating farm operation timing. Operators must adapt their farm planting and harvesting cycles to address the changing duration of growing seasons.

6.2 Crop Varieties

Crop diversification represents an opportunity. Operators should investigate new crops that require a relatively long growing season such as watermelon, tomatoes, peppers, peaches, and European red wine grape varieties (Wolfe et al., 2008). For agricultural operations with long winter chill requirements, operators should consider planting new tree cultivars with reduced chilling requirements and adopting new management practices for breaking dormancy in insufficient winter chill years. From a technical perspective, focus needs to be placed on developing new crop varieties, including hybrids, to increase the tolerance and suitability of plants changing climatic condition (Smit & Skinner, 2002).

Figure 7.6 *Wine varietals by photographer Gary Weber*

6.3 Cover Crops, Tillage Management and Green Manure

One of the central components of conservation agriculture is minimizing soil disturbance by tillage or eliminating tillage once the soil is brought to good condition. These alternative tillage practices address moisture and nutrient deficiencies. In addition, maintaining year-round organic matter cover over the soil, including specially introduced cover crops and intercrops retains residues from the previous crop (Kassam, Friedrich, Shaxson, & Pretty, 2009). Cover crops grown primarily to add organic matter to agricultural production soils are called green manure. The legumes such as clover contain nitrogen fixing symbiotic bacteria that fix atmospheric nitrogen in a form that plants can use. These crops are incorporated into the soil while still green performing the vital functions of fertilization and carbon sequestation (Kassam et al., 2009).

6.4 Pest, Disease, Weed and Invasive Species Management

With changing climate conditions, the need to monitor for pests, diseases and weed outbreaks is heightened. "Those farmers who make the best use of the basics of integrated pest management (IPM) such as field monitoring, pest forecasting, recordkeeping, and choosing economically and environmentally sound control measures will be most likely to be successful in dealing with the effects of climate change" (Petzoldt & Seaman, 2006).

6.5 Farm Design and Water Management

Some farms may benefit from landscape level analysis to address the moisture deficiencies associated with climate change and reduce the risk of farmland degradation from inundation. Farm redesign components may include increased setbacks from rivers or lakes in more vulnerable inundation settings or investment in irrigation and water storage. Conservation buffer strips and riparian corridors help stabilize soils that might be eroded by flooding associated with climate change (Holt-Giménez, 2002; Kominami & Lovell, 2012).

6.6 Energy Efficiency and Farm Based Energy Generation

Given upcoming fossil fuels volatility (Energy Section 4), Crop producers should investigate opportunities to reduce fossil fuel use or increase on-farm energy generation (Wolfe et al., 2008). For marginal lands, farm operations could investigate investment in wind or solar operations in the expanding renewable energy market (Wolfe et al., 2008).

6.7 Hoop Houses and High Tunnels

Given the predicted increased variability of spring and fall temperatures, high tunnels (Figure 7.6) and hoop houses are becoming an increasingly important production tool. A high tunnel or hoop house at its simplest form is a non-permanent structure made from greenhouse plastic and a wood or metal frame. These non-heated devices protect the plants' environment relative to the open field, allowing for earlier or later production of many crops. "Producers, ranging from small-scale market gardens to larger scale farms, are using high tunnels of various forms to produce for early markets, schedule production through extended seasons, grow specialty crops that require some environmental modification, and capture premium prices " (Carey et al., 2009).

Figure 7.7 *Image of High Tunnel from Wikimedia Commons*

7. *Livestock Production Practices*

As described above, animal heat stress lowers overall livestock efficiency. To counter the effects of extreme heat, dairy farm operators can invest in heat management infrastructure. Indoor enhancements include adding sprinkler systems at the feed line, installing fans in interior spaces, and adapting barns to maximize air flow. Pasture adaptations include adding shade or shelter belts to animal grazing areas (Chase, 2006).

Given livestock's role in global greenhouse gas, reduction in emissions from diary and meat producing operations are a part of many climate mitigation plans. Dairy operations should investigate optimizing cow feed or capturing methane created in manure lagoons to reduce enteric methane (McMichael, Powles, Butler, & Uauy, 2007; Wightman, 2006).

Below is information on an ongoing research project at the University of Vermont, Vermont Farm Resilience in a Changing Climate Initiative, which expands on the resiliency information presented above. This initiative not only evaluates the best practice items outline above, but also provides in-depth evaluations of the climate change resiliency practices, assessing their impact on the economic health of farms, their environmental quality, and their preservation.

Box 7.2 Vermont Farm Resilience in a Changing Climate

University of Vermont Participatory-Action-Research collaboration to identify, evaluate and foster implementation on-farm climate change resilience practices.

This long-term University of Vermont initiative is a partnership between Vermont farmers, University extensionists, climate and policy scientists, economists, and agroecologists. This group provides in-depth evaluations of climate change mitigation and adaptation practices and assesses their impact on the economic health of farms, their environmental quality, and their preservation. Their goal is to seek to limit the degree of risk that farmers face due to the changing climate. The three-phase project started in 2012 and intends to be a long-term initiative.

The collaboration's research is in the second phase, comprised of on-farm research and focus groups. The on-farm component's aim is to determine the financial costs and benefits of specific best management practices, as well as measuring the climate change mitigation and/or adaptation potential of each practice. In addition, this second phase involves developing a computer model of land use change to address land use policy, planning and practices in relation to climate change and water quality

The third research phase focuses on validating and disseminating results including on-farm workshops. The facilitation of farmer led, on-farm workshops demonstrates targeted and proven best management practices as part of on-farm climate change adaptation and mitigation. Landscape visualization is employed to help farmers and landowners picture how their fields, farms and the Vermont landscape would change under different management scenarios.

To find out more about Vermont Farm Resilience in a Changing Climate visit vifarmresilience.org.

8. Summary Table Rating Quality of Information

Key Message 1	***Climate change is altering the Vermont growing season. Climate change models project that Vermont's frost-free period will extend by as much as one month by the end of the century. This extended growing season can increase overall crop productivity and create new crop opportunities such as grapes and peaches. This warming could have a negative impact on***

	agricultural shrubs and fruit trees, such as apple, that need a prolonged winter chilling period into order to initiate the flowering process in the spring.
Description of evidence base	Hayhoe, K., Wake, C. P., Huntington, T. G., Luo, L., Schwartz, M. D., Sheffield, J., Wolfe, D. (2007). Past and future changes in climate and hydrological indicators in the US Northeast. *Climate Dynamics*, 28(4), 381–407. Wolfe, D. W., Ziska, L., Petzoldt, C., Seaman, A., Chase, L., & Hayhoe, K. (2008). Projected change in climate thresholds in the Northeastern U.S.: implications for crops, pests, livestock, and farmers. *Mitigation and Adaptation Strategies for Global Change*, 13(5-6), 555–575.
New information and remaining uncertainties	Empirical evidence from Vermont farmers (e.g., Allanholm Farm) also shows a change in seasons. More citizen science of this kind could improve our understanding of the impacts of climate change.
Assessment of confidence based on evidence	Given the evidence base and remaining uncertainties, confidence is **very high** that climate change is altering Vermont's growing season.
Key Message 2	**Climate change models also project greater variations in seasonal temperature and precipitation. Spring time fluctuations could lead to reduced fruit size or frost damage. In addition, excessive soil moisture levels could result in delayed spring planting. During the summer, climate models project more short- and medium-term dry periods for the region. Increased summer dry spells will be occurring at a time when crop water requirements are also increasing due to warmer temperatures.**
Description of evidence base	Hayhoe, K., Wake, C. P., Huntington, T. G., Luo, L., Schwartz, M. D., Sheffield, J., Wolfe, D. (2007). Past and future changes in climate and hydrological indicators in the US Northeast. *Climate Dynamics*, 28(4), 381–407. Wolfe, D. W., Ziska, L., Petzoldt, C., Seaman, A., Chase, L., & Hayhoe, K. (2008). Projected change in climate thresholds in the Northeastern U.S.: implications for crops, pests, livestock, and farmers. *Mitigation and Adaptation Strategies for Global Change*, 13(5-6), 555–575. Hatfield, J. L., Boote, K. J., Kimball, B. A., Ziska, L. H., Izaurralde, R. C., Ort, D., … Wolfe, D. (2011). Climate impacts on agriculture: implications for crop production. *Agronomy Journal*, 103(2), 351–370.
New information and remaining uncertainties	The long-term outcomes are clear, such as the ability to plant new crop varieties. There remains uncertainty as to when these changes will occur. For example, peaches can over winter in Vermont but do not survive a full decade. Time and more research will tell us when winter temperatures will be sufficiently warm for sustaining peach orchards in Vermont.

Assessment of confidence based on evidence	Given the evidence base and remaining uncertainties, confidence is **high** that extremes in weather will continue to increase as climate changes in Vermont.
Key Message 3	**Changes in atmospheric carbon dioxide and tropospheric ozone will also impact Vermont's agriculture. Enhanced atmospheric CO_2 promotes photosynthesis, potentially fueling the growth of many Vermont plant varietals. On the other hand, tropospheric ozone is projected to adversely affect the productivity of agricultural crops in Vermont.**
Description of evidence base	McGrath, J. M., & Lobell, D. B. (2013). Regional disparities in the CO2 fertilization effect and implications for crop yields. *Environmental Research Letters*, 8(1), 014054. Twine, T. E., Bryant, J. J., T. Richter, K., Bernacchi, C. J., McConnaughay, K. D., Morris, S. J., & Leakey, A. D. B. (2013). Impacts of elevated CO2 concentration on the productivity and surface energy budget of the soybean and maize agroecosystem in the Midwest USA. *Global Change Biology*, 19(9), 2838–2852. Felzer, B., Kicklighter, D., Melillo, J., Wang, C., Zhuang, Q., & Prinn, R. (2004). Effects of ozone on net primary production and carbon sequestration in the conterminous United States using a biogeochemistry model. *Tellus B*, 56(3), 230–248. Booker, F., Muntifering, R., McGrath, M., Burkey, K., Decoteau, D., Fiscus, E., Grantz, D. (2009). The Ozone Component of Global Change: Potential Effects on Agricultural and Horticultural Plant Yield, Product Quality and Interactions with Invasive Species. *Journal of Integrative Plant Biology*, 51(4), 337–351. Izaurralde, Thomson, Fay, & Morgan. (2011). Climate Impacts on Agriculture: Implications for Forage and Rangeland Production. *Agronomy Journal*.
New information and remaining uncertainties	We lack information on changes in Vermont's tropospheric ozone levels, which will impact the extent of damages. Policies to reduce ozone formation, such as electric cars and public transportation, could drastically reduce the ozone burden on crops.
Assessment of confidence based on evidence	Given the evidence base and remaining uncertainties, confidence is **very high** that additional CO_2 in the atmosphere will boost crop yields and **high** that surface level ozone will damage crops.
Key Message 4	**For Vermont livestock operations, summer heat stress could lead to decreases in livestock productivity, but most pronounced operational impacts arise from increased feed and energy costs. Climate change impacts on these indirect costs make the industry vulnerable.**

Description of evidence base	Berman, A. (2005). Estimates of heat stress relief needs for Holstein dairy cows. *Journal of Animal Science*, 83(6), 1377–1384. Wheeler, T., & Reynolds, C. (2013). Predicting the risks from climate change to forage and crop production for animal feed. *Animal Frontiers*, 3(1), 36–41.
New information and remaining uncertainties	The cost of energy to livestock opperations depends on future energy sources and technology that conserve energy on farms. Analysis of future scenarios of indirect costs to farms would provide more information on vulnerabilities.
Assessment of confidence based on evidence	Given the evidence base and remaining uncertainties, confidence is **high** that climate change will impact indirect costs to Vermont's livestock operations.
Key Message 5	**The projected higher incidence of extreme weather events can create floods that degrade and inundate farms and livestock operations. If the flooding occurs during the growing season, crops can be lost due to diseases and soil compaction. In addition,** *extreme weather events can result in damage to planting beds, furrows, ditches, and other agriculture-related infrastructure.*
Description of evidence base	Jackson, L., Wheeler, S., Hollander, A., O'Geen, A., Orlove, B., Six, J., Tomich, T. (2011). Case study on potential agricultural responses to climate change in a California landscape. *Climatic Change*, 109, 407–427. Wolfe, D. W., Ziska, L., Petzoldt, C., Seaman, A., Chase, L., & Hayhoe, K. (2008). Projected change in climate thresholds in the Northeastern U.S.: implications for crops, pests, livestock, and farmers. *Mitigation and Adaptation Strategies for Global Change*, 13(5-6), 555–575.
New information and remaining uncertainties	Management and policies to project farmlands could mitigate the impacts of extreme events.
Assessment of confidence based on evidence	Given the evidence base and remaining uncertainties, confidence is **high** that increased frequency of extreme weather events will have physical impacts of Vermont farms.
Key Message 6	***Given the upcoming climate changes, it is essential that Vermont agriculture enterprises develop forward looking adaptation plans. Farm production programs that address climate change include changing operational timing, investigating new crops and new varietals, increasing cover crop and minimal tillage practices, landscape level farm and increasing farm energy efficiency. Some Vermont agricultural endeavors will adapt to climate change more easily depending on farm production***

	practices and location. The overall impact on Vermont livestock and crops will depend on the collective rate of adaptation.
Description of evidence base	Chapter 3, this Chapter.
New information and remaining uncertainties	The overall impact on Vermont livestock and crops will depend on the collective rate of adaptation.
Assessment of confidence based on evidence	Given the evidence base and remaining uncertainties, confidence is **very high** that adaption to climate change will determine the impacts climate change has on Vermont's farms.
Key Message 7	**Many greenhouse gas emissions stem from agricultural management choices so agricultural producers can play an active role in greenhouse gas mitigation. Common mitigation areas include improving carbon sequestration in biomass and soils, decreasing fuel/ fertilizers input, and reducing methane emissions from livestock production.**
Description of evidence base	Melillo, J. M., et al. (2014). Climate Change Impacts in the United States: The Third National Climate Assessment. Washington, DC, U.S. *Global Change Research Program:* 841.
New information and remaining uncertainties	Innovations, such as biogas capture and use, may reduce emissions from agriculture in the future. Vermont is not a large greenhouse gas emitter and most emissions are from transportation and energy so reductions in agricultural emissions could have a small impact.
Assessment of confidence based on evidence	Given the evidence base and remaining uncertainties, confidence is **high** agricultural producers can help reduce Vermont's greenhouse gas emissions
Key Message 8	***When developing agricultural adaptation and mitigations policies, it is essential to include small to medium sized agricultural enterprises in planning. Small agricultural businesses are particularly vulnerable to climate change due to the physical concentration of assets and limited overall financial resources.***
Description of evidence base	This Chapter.
New information	This risk could be minimized by public and private support, such as grants and loans, extension consultation and such.

and remaining uncertainties				
Assessment of confidence based on evidence	Given the evidence base and remaining uncertainties, confidence is **very high** that small agricultural businesses are vulnerable to climate change.			

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Chapter 8: Recreation and Tourism

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Key Messages

Winter:

- **In the coming two decades, mountain snowfall may increase with increasing winter precipitation, which would have a positive impact on winter-related recreation and tourism industries. However, variability of snowfall from year to year may also increase.**
- **Within 30-40 years, average winter temperatures will have increased to the point that most winter precipitation falls as rain, which will result in shorter lasting snowpack and snowfall, reducing the winter tourism and recreation seasons. This will negatively impact winter-based industries such as skiing, snowmobiling and ice fishing. Later snowfalls and ice-ups are likely to particularly affect the Christmas/New Year's holiday tourism season.**
- **The Vermont alpine ski industry has moved quickly to mitigate and adapt to climate change. Adaptation activities have focused on expanded artificial snowmaking capabilities and increased year-round recreational opportunities. In addition, it competes as "green" and "sustainable" in the regional market.**
- **Climate change could actually help the Vermont alpine ski industry as more southerly and lower elevation ski areas in other states become unviable. Some projections suggest all 18 remaining ski areas in Vermont will be economically viable through 2075, even under high greenhouse gas emissions scenarios.**

Summer:

- **The summer tourism and recreation season will lengthen, and increased temperatures, combined with high humidity, are expected to drive more tourists to Vermont, presenting an opportunity for summer tourist destinations to expand their activities and businesses.**
- **Hotter weather with more severe rain events may dampen recreation and tourism activities slightly, but Vermont's State Parks expect more visitors as a result of climate change, not less.**
- **Water-based recreation (boating, fishing, swimming) may suffer from higher water temperatures, which can increase algal blooms in lakes and reduce populations of cold-water fish (e.g. trout). On the other hand, warmer waters may improve and lengthen tourists' summer experience in Vermont's lakes.**
- **Increased temperatures will encourage expansion of pest species (e.g. ticks and mosquitos), reducing the quality of the recreation experience.**

Autumn:

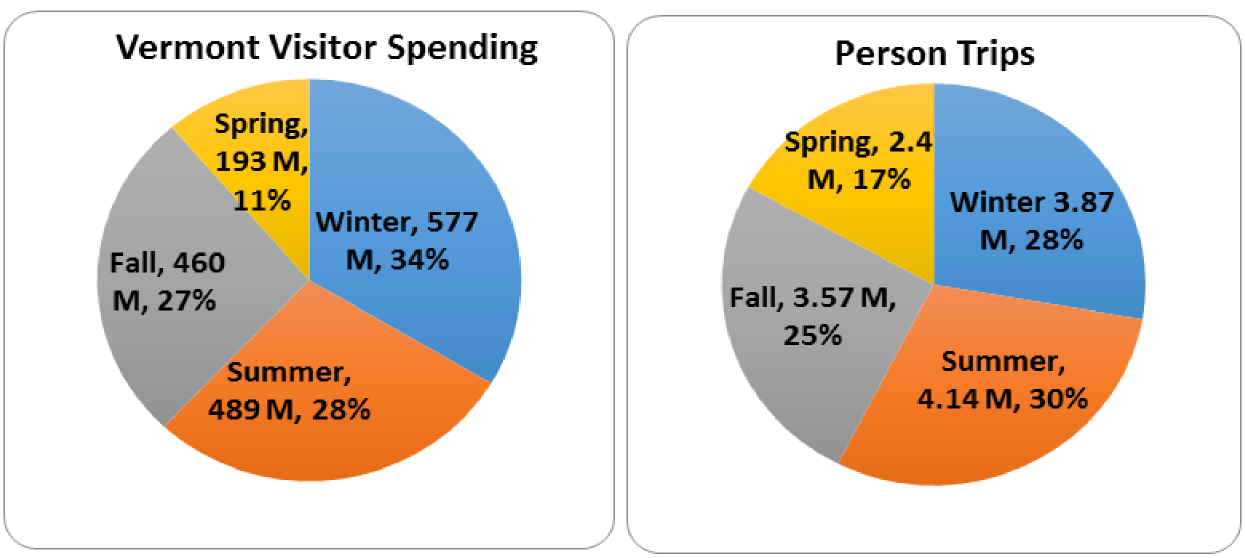
- **The Fall foliage season may start later and last a little longer as leaves remain on the trees longer due to warmer temperatures. However, the intensity of foliage color may be reduced as frosts come later. Higher temperatures may attract more tourists for the foliage season and harvest-time, particularly those from southern climates, which would be positive for tourism.**
- **Warmer temperatures will extend the fall recreation season for hiking, biking, boating, camping and hunting, which will have a positive effect on tourism.**

1. Introduction

Recreation and tourism go together in Vermont. As stated in the 2001 Benchmark Study of the Economic Impact of Visitor Expenditures on the Vermont Economy (Chmura Economics and Analytics), "Tourism-related spending is very dependent on the weather", which in large part determines recreational opportunities and driving conditions (75% of tourists come to Vermont by car). While tourism specifically to visit Vermont's cities and towns is an important part of the economy, the majority of Vermont's tourism is to enjoy Vermont's excellent outdoor recreational opportunities. As climate change affects those recreational opportunities in both positive and negative ways, it can be expected that tourism will rise and fall in a strongly correlated fashion. Overall, the assessment offered in this chapter suggests that Vermont's tourism and recreation industries should remain strong, with some seasonal adaptations to be made.

Figure 8.1 below shows visitor spending in Vermont by season in 2011. Out of a total of $1.7 billion, the winter season accounts for 34% ($577 M), the summer season produces 28% ($489 M), fall generates 27% ($460 M), and the spring, just 11% ($193 M). Visitor spending supports an estimated 38,000 jobs for Vermonters (more than 11% of all jobs in Vermont), and contributed $275 million in tax and fee revenues to the State (Chmura, 2011). Clearly, tourism is a major

Figure 8.1 *Vermont visitor spending (US$ Millions; left) and Person Trips (Millions; right) in 2011 (Chmura Economics and Analytics 2011).*



driver of Vermont's economy and employment opportunities, and considered as the 5th most important industry in the state in terms of employment.

Figure 8.2 shows the number of person-trips by season in 2011. Out of a total of nearly 14 million person-trips, the summer accounted for the most visits (30%), followed by winter (28%), fall (26%) and spring (17%). The differences in these seasonal percentages compared to Figure 8.1 is explained by increased spending person during the winter and fall compared to summer and spring (Chmura 2011). The rest of this chapter examines potential changes in seasonal tourism and recreational opportunities with the exception of spring, which draws relatively few visitors.

A variety of methodologies exist for estimating Vermont's future climate as it affects recreation and tourism, including application of computer models (involving either statistical or dynamical downscaling from models developed to simulate global climate change) and extrapolation from previous observed climate trends. This chapter adopts the second approach and draws heavily on observations by the National Weather Service in Burlington, Vermont and the work of Alan Betts, specifically "Vermont Climate Change Indicators" (published in the journal *Weather, Climate and Society*, Vol. 3, 2011). It should be noted that the projections made based on observed historical trends closely match the projections made based on the IPCC-AR4 model, which produced specific scenarios for the Northeastern United States.

2. Winter Tourism and Recreation

Generally speaking, it is expected that both temperatures and precipitation in Vermont will increase due to climate change. For Vermont's winter recreation and tourism business, what really matters is how both of these trends interact with the freezing point. In other words, so long as temperatures remain below 32° Fahrenheit (0° Celsius), increased precipitation may mean greater snowfall and increased economic activity related to snow-based recreation and tourism. But once the 32° threshold is reached, increased precipitation means increased rain, which can quickly wash away existing snow. Higher elevations are colder, so Vermont's mountainous areas may benefit from increased snowfall.

Furthermore, there is an important positive feedback mechanism between how much snow is on the ground and how cold it is: snow acts to reflect the sun's rays and maintain cooler temperatures on local scales (the albedo effect). If snow cover melts, solar reflection decreases, the earth's surface absorbs more heat and the snow melts further. Simultaneously, warmer temperatures increase evaporation and atmospheric water vapor, which increases the greenhouse effect at the local scale (increasing downward re-radiation of infrared heat initially radiated off the earth's surface), further increasing local temperatures (Betts et al, 2014.

Figure 8.3 shows mean temperatures during the winter during the period 1960-2010, which have increased by about 4.5° F (2.1° C). While there is considerable variability (more so than in the summer), regression trend lines indicate that winter mean temperatures are increasing by almost 1 degree Fahrenheit per decade (specifically, 0.91° ± 0.28° F). This trend over the past 50 years

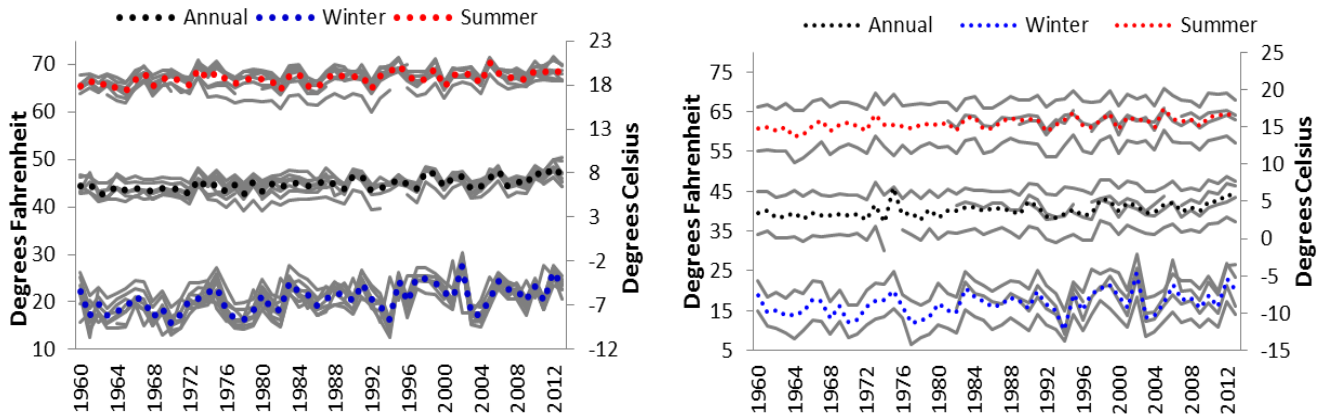
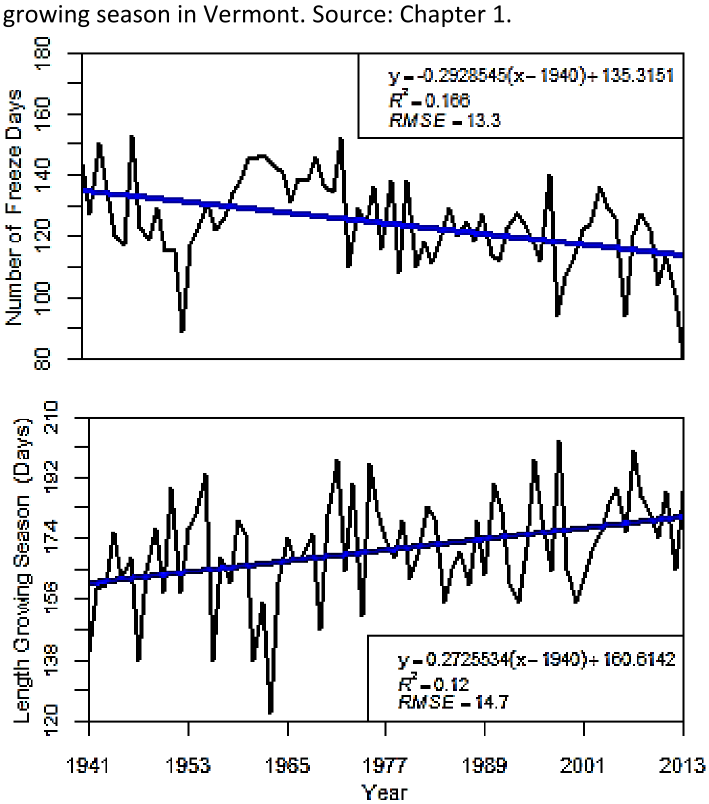


Figure 8.3. *Annual, winter, and summer average temperature change from 1960-2013 for lowland (left) and highland (> 1000 ft; right) climate sites in Vermont. Note the high amount of variability in average winter temperatures. Source: Chapter 1.*

can be considered as likely first estimates for Vermont for the next 40 years, although it is expected that this upward temperature trend will accelerate as the impacts of CO2 emissions over the past 30 years work their way through the global energy cycle lag times into increased air temperatures. If this is true, winter mean temperatures can be expected to increase by at least another 4° F (1.9° C) by 2050, with more winter days above the freezing point.

Not surprisingly, higher winter mean temperatures have reduced the freeze-period significantly since 1960, as can be seen in Figure 8.4. Assuming this trend continues, this will result in shortened seasons for skiing, snowmobiling, ice fishing and showshoeing. While still a long ways off, by the end of the century the average number of reliable snow-covered days in Vermont is expected to decrease to as few as 13-25 days (Frumhoff et al. 2007). This loss of reflective snow cover will substantially increase winter temperatures. The declining freeze-period is particularly critical for winter sports that rely on natural snow and ice cover (most Vermont ski areas now make large amounts of artificial snow, so long as temperatures permit and there is reliable water access, but this is energy-intensive and costly). In addition, the end-of-year holiday season is very important economically, generating as

Figure 8.4 Decline in the frozen period and lengthening the growing season in Vermont. Source: Chapter 1.



much as one-third of a ski resort's annual revenue (Dunnington, 2011). A late arriving winter and/or one with more rain or freezing rain in late December/early January could seriously cut into revenues of both ski resorts and the winter hotel industry.

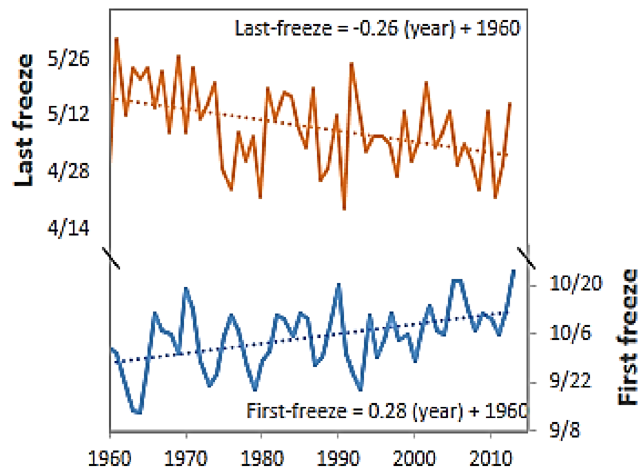
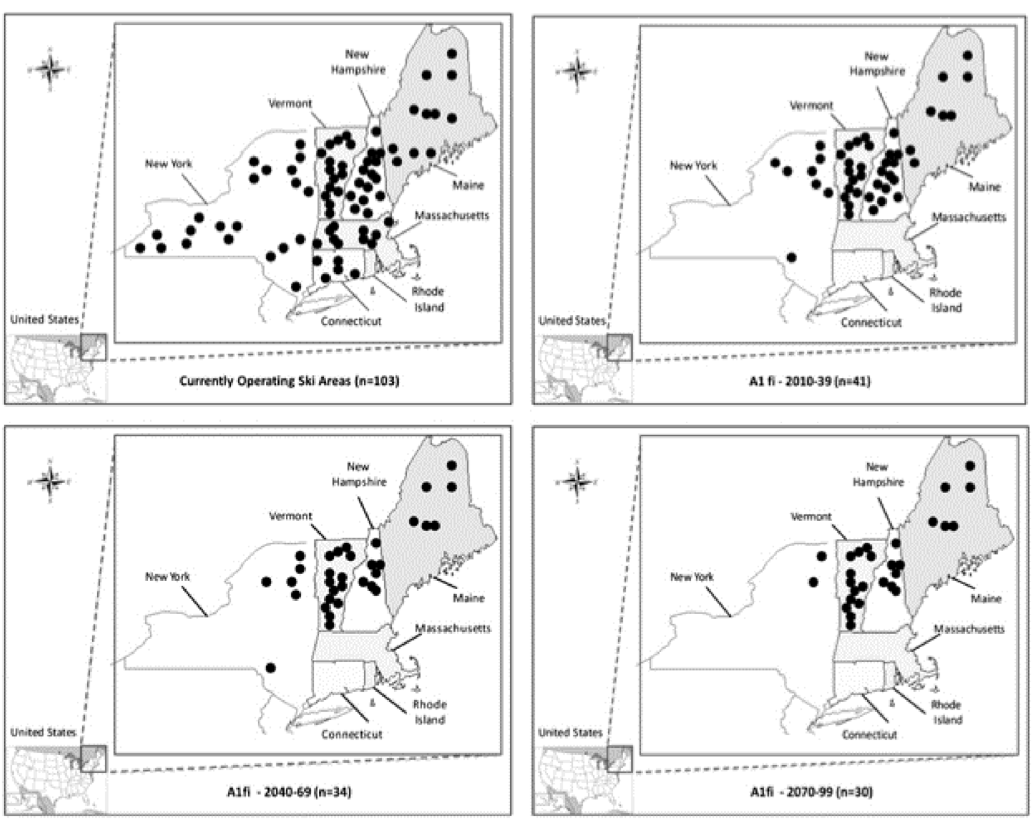


Figure 8.5. *Declining frozen period in Vermont. Source: Chapter 1.*

In 2007 a vulnerability assessment of Vermont's 18 ski areas was carried out (Dawson and Scott, 2007), applying six different climate change scenarios. It is generally accepted that ski areas need to operate at least 100 days per season to be economically viable, with the most crucial period being the Christmas/New Year holiday period. Applying these two broad economic risk criteria, only two low-elevation ski areas (Cochran's and Suicide Six) were considered highly vulnerable to climate change. However, under all scenarios and for all ski areas, shortened ski seasons and increased snowmaking requirements were projected.

Figure 8.6 *Contraction of US Northeast ski area under a high emissions scenario (Dawson and Scott 2013)*



Further analysis of the vulnerability of 103 ski areas in six northeastern states (Vermont, New Hampshire, Maine, New York, Massachusetts, Connecticut), was conducted (Dawson and Scott, 2013), applying the Intergovernmental Panel on Climate Change (IPCC) scenarios for low and high carbon emissions. The four maps shown in Figure 8.6 corresponds to four time periods: 2010, 2010-2039; 2040-2069; 2070-2099. Under the high emissions scenario and using the same economic viability criteria described above, the authors project a major contraction from 103 to just 30 ski areas by 2075 (35 would survive under the low emissions scenario). But 18 of those ski areas are projected be in Vermont, which is a very positive sign.

The popular Joe's Pond ice-out observations shown in Figure 8.7 clearly suggest that ice fishing, in particular, will be less accessible in the future. The ice-out date and time on Joe's Pond in Danville, Vermont is determined by the moment a cinder block wired to a wooden pallet placed on the ice 100' out from shore falls into the water. The block is tethered to an electric clock and when it goes down the clock disconnects, and that is the official "ice-out time". While perhaps not the most scientific method for measuring declining freeze periods, it is nonetheless reliable observational data that agrees with a longer-term record at Stiles Pond. The 25-year trend since 1988 is clearly towards earlier ice-out dates, although there is significant variation year to year.

With respect to precipitation, it is more difficult to project than temperature. But both the global model and observed historical trends anticipate significant increases, by as much as 15% during winter months by 2090 compared to 2000, with large annual variability (Betts, 2011a). The frequency of heavy precipitation events is also expected to increase; during the period 1958-2007 the amounts of very heavy precipitation increased by 67% in the northeastern United States. This suggests that future snowfall will increasingly be concentrated in large events, as opposed to more frequent but less bountiful snowstorms.

Figures 8.7-8.11 show trends in precipitation in Vermont during the three-month winter period January-March from 1960-2013. Figure 8.7 shows the overall statewide trend (increasing by about 0.33" per decade, with increasing annual variability). Figure 8.8 shows the trend in Northeastern Vermont (increasing by almost 0.50" per decade). Figure 8.9 shows Western Vermont (increasing by 0.28" per decade). Figure 8.10 shows Southeastern Vermont (essentially no increase), and Figure 8.11 shows Burlington (increasing by 0.20" per decade). All figures except that for Southeastern Vermont show both increasing precipitation and increasing variability.

Figure 8.7. *Joe's Pond Ice Out Dates. Source: Chapter 1*

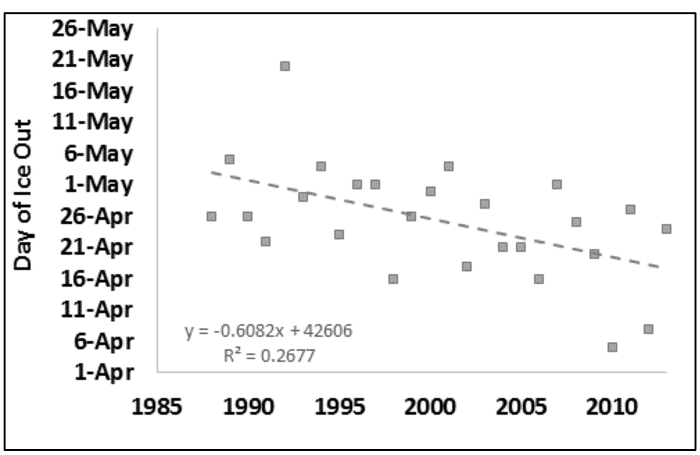


Figure 8.8. *Vermont Precipitation Trends for the 3-month Period, January-March, 1960-2013 (NWS 2014).*

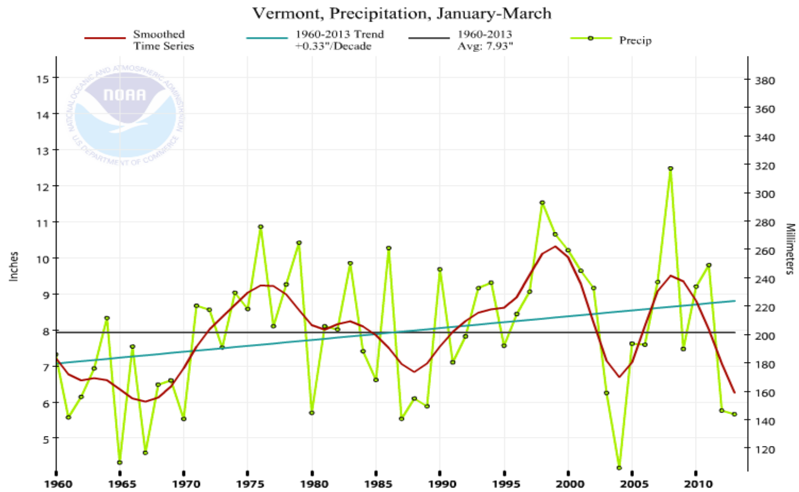


Figure 8.9. Northeastern *Vermont Winter Precipitation Trends, 1960-2013 (NWS 2014).*

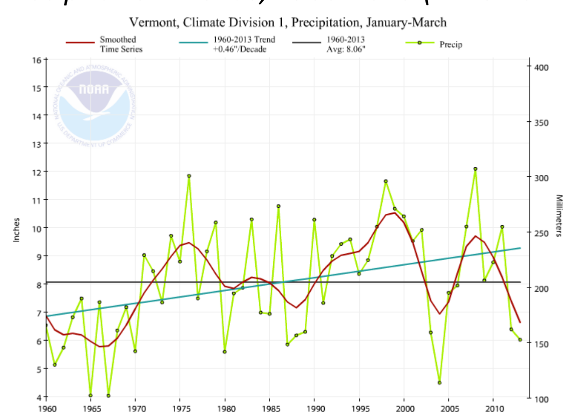


Figure 8.10. Western *Vermont Winter Precipitation Trends, 1960-2013 (NWS 2014).*

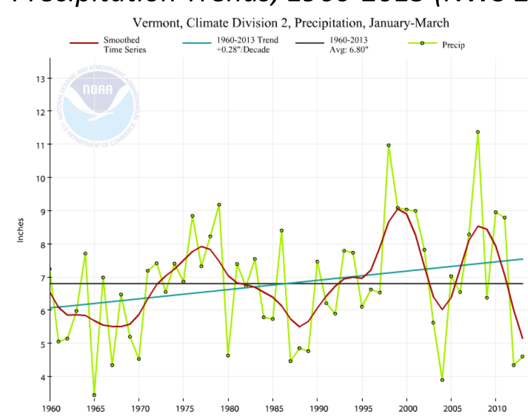


Figure 8.11. Southeastern *Vermont Winter Precipitation Trends, 1960-2013 (NWS 2014).*

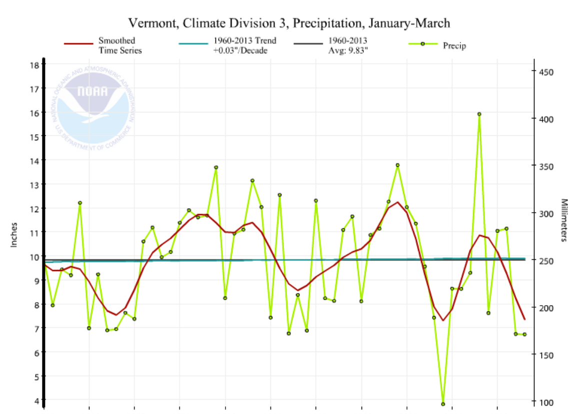


Figure 8.12. Burlington *Vermont Winter Precipitation Trends, 1960-2013 (NWS 2014).*

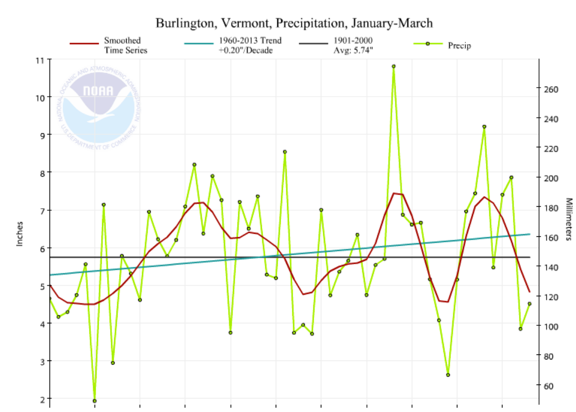
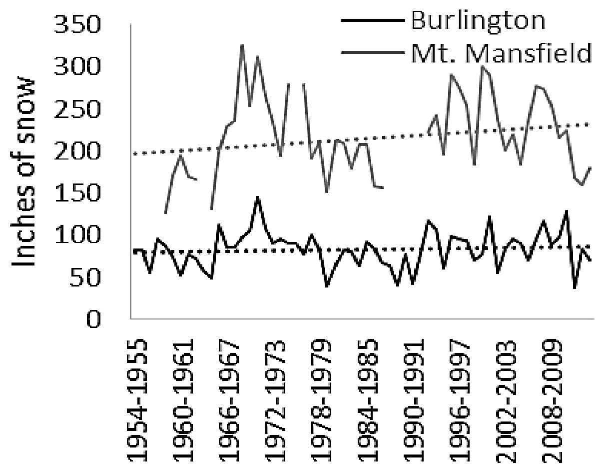


Figure 8.13 *Snowfall in Burlington and Mt. Mansfield 1954-2013.*



Based on observed historical temperature trends in Vermont, winter mean temperatures are projected to remain below the freezing point until at least 2050. This suggests that over the next 30 years Vermont might benefit from increased overall snowfall (as precipitation increases), particularly in higher elevation mountainous areas, until such time as average increasing winter temperatures convert more of this increased precipitation into rain and freezing rain. Over the near-term, this could create a "sweet spot" for Vermont winter recreation and tourism, as can be observed in Figure 8.13 which shows total winter snowfall (measured in inches) at Mount Mansfield and in Burlington. The 22% increase at Mount Mansfield over this time period is particularly noteworthy. Moreover, Vermont's alpine ski areas have moved aggressively to mitigate and adapt to climate change, in described in the Text Box 8.1 below.

Text Box 8:1: Case Study of Climate Change Mitigation and Adaptation by the Vermont Ski Industry

The Vermont ski industry has moved quickly to both mitigate and adapt to climate change. In terms of mitigation, the industry has invested millions of dollars in more energy-efficient buildings and snowmaking. According to Ski Vermont (the industry association), these investments have saved more than $26 million in electrical and fossil fuel consumption and prevented over 150,000 tons CO2-e emissions. Renewable energy generation to power ski lifts and lodges has expanded to include solar, wind and methane digesters (cow manure), although these account for a small percentage of overall energy usage by the ski industry. Increased tree planting (e.g. Jay Peak's partnership with the Clear Water Carbon Fund) at ski areas increase carbon sequestration and storage, and improve water quality.

With respect to adaptation, ski areas have invested tens of millions of dollars in expanded artificial snowmaking and increased grooming capacity to compensate for warmer temperatures and to provide greater predictability for skiers, allowing them to open earlier and close later than they would otherwise with only natural snowfall. Improved micro-climate weather forecasting allows ski areas to prepare for and respond quickly to changing weather conditions, for example, making snow at optimum times and grooming trails strategically to retain as much snow as possible. Finally, more and more ski areas are converting into four-season destinations, with golf courses, alpine slides, water parks, music events, car shows, etc. While winter activities still account for more than 75% of total ski resort revenues, diversification of recreational opportunities to year-round operations may make up for losses due to reduced snowfall and/or higher winter temperatures.

Vermont's ski industry is attempting to convert the challenge of climate change into a competitive opportunity, marketing itself as the "green" ski state to persuade people who might otherwise ski in Maine, New Hampshire or New York State to come to Vermont. For example, Stowe Mountain Resort is the first and only ski resort in North America to become a "Certified Sustainable Destination" by Audubon International. And Killington Resort was awarded the 2013 Golden Eagle for Environmental Excellence from the National Ski Areas Association. Beyond energy measures, large-scale recycling and composting programs have been established, reducing pressure on landfills, and increasing the overall sustainability of the industry. More than 15 ski areas in Vermont have obtained some form of certification of sustainability and/or energy efficiency, which is used for branding, advertising and marketing.

Over the next 20 years the expected increased precipitation may increase snowfall and (along with expanded artificial snowmaking) increase the number of skier-days in Vermont. On the other hand, it may become increasingly difficult to attract potential new skiers to the sport, who might be dissuaded by reports of global warming and/or unable to afford the increased costs of lift tickets due to increased snowmaking and grooming. The industry will need to continue to respond quickly to the challenge of climate change with even greater mitigation and adaptation measures in the decades ahead.

Source: SkiVermont

3. Summer Tourism and Recreation

Climate change is likely to expand summer tourism and recreational opportunities, as the summer season lengthens. Activities such as camping, hiking, mountain and road biking, fishing, boating and swimming are expected to be available longer for visitors and residents alike. While summer is already the seasonal leader in terms of the number of person-trips per year (4.2 million out of 14 million, in 2011), climate change is likely to expand this lead further. And although

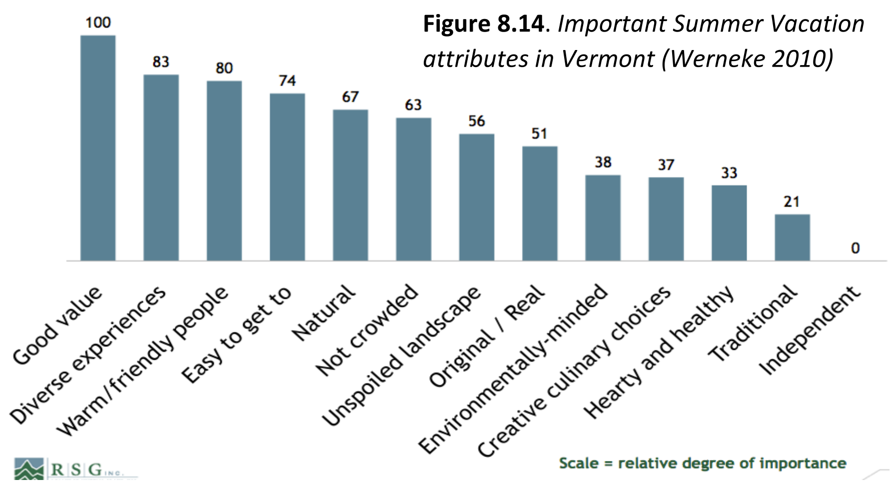


Figure 8.14. *Important Summer Vacation attributes in Vermont (Werneke 2010)*

per person spending is lower in summer than winter ($118 per person trip versus $149 per person trip in 2011), the quantitative increase in the number of visitors during the Summer may more than offset any decrease in winter visits related to climate change, such that it generates a net gain for the Vermont economy overall.

With respect to Vermont's State Parks, visitation is driven largely by weather and the school calendar.[8] While the school calendar may not be affected by climate change (despite its historical roots in the agricultural calendar), summertime weather will be. Figure 8.14 shows the relative ranking of Vermont attributes explaining why vacationers come to Vermont in the summer (the scale is the relative degree of importance). Worth noting is that none of the most important attributes are climate-dependent, which suggests that summer tourism should remain quite robust.

On the negative side, warmer water temperatures will result in increased algal blooms in lakes (unless the runoff of phosphorus and nitrogen fertilizers is reduced in the future), and more frequent intense storm events will generate higher rainfall and runoff. In addition, warmer temperatures are expanding the populations of certain pests in Vermont, which used to thrive only further south, such as ticks causing Lyme Disease. Increased populations of mosquitos (linked to higher temperatures and precipitation) may also increase the risk of Eastern equine encephalitis (EEE) and the West Nile virus. Certain irritating flora such as poison ivy may also spread more quickly in Vermont as a result of climate change. All of these risks may lessen the visitor experience and even dissuade visitors from travelling to Vermont in the first place, requiring increased management and adaptation.

On the positive side, higher mean summer temperatures in lower New England states and New York may drive more visitors to Vermont seeking higher elevations and cooler weather. While Vermont's summer water quality problems have been well documented in recent reports (see Chapter 5 on Water), overall water quality for swimming, boating and fishing remains very good, as shown in weekly water monitoring in all of Vermont's State Parks. Furthermore, the risks related to pests and irritating flora mentioned in the paragraph above are all present in the states most visitors come from to Vermont (Massachusetts, New York, Connecticut, New Jersey, etc.), so many visitors may be well-adapted to them already.

An interesting perspective is that summertime tourism and recreation in Vermont appears to be counter-cyclical to overall economic growth in the country. It represents a lower cost summer vacation opportunity for many potential visitors (e.g. camping on Burton Island versus a trip to Disneyland), so any large-scale negative economic effects of climate change on potential visitors residing in states south of Vermont (e.g. another Hurricane Sandy), or simply overall stagnant economic growth, may actually generate positive local-scale economic impacts in Vermont.

Overall, summer tourism and recreation adaptation strategies would include: (i) rehabilitation and expansion of facilities to accommodate more summertime visitors to Vermont's State Parks

[8] Phone conversation with Craig Whipple, Director of Vermont State Parks, October 17, 2013.

and tourist sites; (ii) continued careful monitoring of Vermont's water quality; and (iii) enhanced monitoring and treatment of summertime pests.

4. Fall Tourism and Recreation

While the fall season is in third place behind winter and summer in terms of both tourism spending and number of person-trips, it nonetheless represents a very important component of the overall tourism industry. Vermont's spectacular fall foliage is a big draw, as is apple-picking, farm visits, hunting and fishing. Warmer mean temperatures in the fall are likely to attract more visitors to Vermont, who will be able to enjoy outdoor recreational activities longer in the year. In addition, while the fall foliage colors are primarily determined by changing hours of sunlight, warmer temperatures and increased precipitation may lengthen the time leaves remain on the trees, which could give an additional if minor boost to fall tourism. On the other hand, warmer temperatures threaten Vermont's iconic sugar maples with heat stress and pest outbreaks (see Chapter 6 on Forests), which could reduce the quality of fall foliage viewing experience.

Table 8.1 below shows the key outdoor activities for vacationers in Vermont by season. Most popular fall activities include hiking, camping, fishing, boating, wildlife viewing and biking (road and mountain). Biking, in particular, is an increasingly popular activity around the country, so it can be expected that biking tourism in Vermont will continue to grow. In addition, as climate change keeps Vermont's waters warmer longer, the boating/water sports season will extend, although warmer waters may eventually eliminate cold-water fishing (e.g. lake salmon and trout) activities.

Table 8.1 – Outdoor Activities in Vermont by Season (Percentage of Vermont Vacationers Surveyed Who Reported They Engaged in This Activity) (Werneke, 2010)

Outdoor Activity	Winter/Spring	Summer/Fall
Hiking	25	24
Camping	9	10
Fishing	7	11
Mountain/rock climbing	6	5
Viewing a sporting event	5	4
Adventure games (e.g. paintball)	4	1
Hunting	2	1
Picknicking	-	13
Boating/Water Sports	-	12
Bird/Wildlife viewing	-	10
Road and Mountain biking	-	10
Running/Jogging	-	6
Golf	-	4

Tennis	-	2
Alpine skiing/Snowboarding	46	-
Nordic skiing	6	-
Telemark skiing	2	-
Snowshoeing	7	-
Ice Skating	6	-
Ice Fishing	3	-
Snowmobiling	6	-
Dog Sledding	2	-
Other activities	9	7

On the other hand, looking back at the recent past, Hurricane Irene and Tropical Storm Nicole were both major climatic events, which significantly damaged Vermont's tourism infrastructure (roads, bridges, etc.) and deterred visitors in both September and October 2011. To the extent that climate change results in increased frequency of severe weather events in the future, fall tourism and recreational opportunities could suffer. There is nothing that the tourism and recreation industries can do to prevent these events, but they should be prepared to endure them with less damage and to work with state tourism marketing authorities to encourage vacationers to come to Vermont once the extreme weather has passed.

5. Conclusion

The net result of both positive and negative impacts of climate change on Vermont's tourism and recreation is difficult to project. While it is difficult to model the natural world, which is subject to physical and biochemical processes, it is even more problematic to model future tourism and recreation because they reflect the social world and less predictable human behavior. Overall, the outlook is stable.

Table 8.2 provides a sensitivity analysis and illustrates how hypothetical variations (relative to 2011) in tourism visits and revenues by season for 2025 and 2050 could balance out to keep overall revenues steady. Assuming per trip spending remains constant in real terms and that all variation is with respect to the number of visits in each season, the table indicates the increases in summer and fall tourism required to offset potential declines in winter tourism so that total tourism revenues remain at least at their 2011 levels.

Table 8.2: *Sensitivity Analysis –Increases in Summer and Fall Tourism Required to Offset Hypothetical Declines in Winter Tourism, 2025 and 2050 (Author's calculations)*

	2011	**2025**			**2050**		
	Baseline Revenues ($ M)	Variation	Person Trips (M)	Revenues (2011$ M)	Variation	Person Trips (M)	Revenues (2011$ M)
Winter	577	-10%	3.5	519	-20%	3.1	461
Summer	489	10%	4.6	537	18%	4.9	576
Fall	460	3%	3.7	471	7%	3.8	489
Spring	193	0%	2.4	193	0%	2.4	193
TOTAL	**1719**			**1720**			**1720**

While purely hypothetical, this rather simple sensitivity analysis suggests Vermont tourism and recreation should remain healthy overall, but that continued adaptation will be required in the decades ahead. More positively, if winter temperatures remain cold enough so that more of the projected increased precipitation falls as snow, winter tourism might actually increase (rather than decrease as shown in Table 8.2), such that overall tourism and recreation revenues would increase over 2011 levels in real terms. In any case, as recent Vermont tourism brand research suggests (Werneke, 2010), one-season Vermont vacationers need to be converted to multi-season vacationers, and Vermont's perceived unique tourism attributes (good value; warm, friendly people; unspoiled landscape; easy to get to) should be increasingly emphasized by the tourism and recreation industries.

6. Summary Table Rating Quality of Information

Key Message 1	Over the next two decades, increased wintertime precipitation may increase mountain snowfall levels (so long as temperatures remain below the freezing point), which would have a positive impact on winter-related recreational opportunities and tourism industries (e.g. skiing). Evidence base: Observed temperature and precipitation trends by the National Climatic Data Center of the National Oceanic and Atmospheric Organization (www.ncdc.noaa.gov) and the National Weather Service (Burlington, Vermont). Remaining Uncertainties: The actual future interaction of projected increased precipitation and temperatures during winter months is uncertain, particularly at different elevation levels. The projections offered here are based on observed historical trends, not on downscaled climate change computer

	models. Furthermore, many winter tourists come from southern New England states and New York. Whether they will come to Vermont for snow-based activities when they have less snow outside their own homes is highly uncertain. Assessment of confidence based on evidence: **High**
Key Message 2	Increased average mean temperatures and increased precipitation over the next 30-40 years will shorten the winter tourism and recreation seasons, with related negative impacts on winter-based industries such as Nordic skiing, snowmobiling and ice fishing. Later snowfalls and ice-ups are likely to particularly affect the Christmas/New Year's holiday tourism season. Evidence base: Observed temperature and precipitation trends by (i) the National Weather Service (Burlington, Vermont); (ii) Betts, A.K., Vermont Climate Change Indicators, *Weather, Climate and Society*, Vol. 3, 2011; and (iii) Betts, et. al. (2014). Remaining Uncertainties: Similar to Key Message 1, the actual future interaction of projected increased precipitation and temperature during winter months is uncertain, particularly at different elevation levels. The projections offered here are based on observed historical trends, not on downscaled climate change computer models. Furthermore, many winter tourists come from southern New England states and New York. Whether they will come to Vermont for snow-based activities when they have less snow outside their own homes is highly uncertain. Assessment of confidence based on evidence: **Very High**
Key Message 3	The alpine ski industry has already moved quickly to mitigate and adapt to climate change, competing as "green" and "sustainable". Evidence base: Descriptions of specific ski resort environmental efforts downloaded at www.skivermont.com on October 8, 2013. Phone conversation with Parker Riehle, CEO, Ski Vermont on October 8, 2013; www.nsaa.org/media, downloaded on November 5, 2013. Remaining Uncertainties: It is not clear whether competing as "green" and "sustainable" in the northeastern ski market will produce benefits in excess of costs. Vermont's ski areas have invested large sums of money to adapt to climate change, but future skier behavior (current and potential new skiers) is largely unpredictable.

	Assessment of confidence based on evidence: **Very High**
Key Message 4	Climate change could actually help the Vermont alpine ski industry as more southerly and lower elevation ski areas in other states become unviable. Projections indicate all 18 remaining ski areas in Vermont will be economically viable through 2075, even under high emissions scenarios. Evidence base: Dawson and Scott (2013); Observed temperature and precipitation trends by (i) the National Weather Service (Burlington, Vermont) and (ii) Betts et al. (2011a, b). Remaining Uncertainties: Climate change adaptation by the alpine ski industry is highly dependent on artificial snow-making, which is costly and energy-intensive. Ski areas pass these increased costs on to skiers in the form of higher prices; if energy prices rise significantly over the medium term (which is a distinct possibility) so will ski resort prices. It is not clear how continually rising prices will affect overall demand. In addition, given the broader national discussion regarding climate change, young people may be dissuaded from taking up the sport in the first place because local "beginner" ski areas in southern New England and New York may become unviable and potential skiers perceive the sport is unsustainable. Assessment of confidence based on evidence: **High**
Key Message 5	The summer tourism and recreation season will lengthen, and increased temperatures and rainfall further south are expected to drive more tourists to Vermont, presenting an opportunity for summer tourist destinations to expand their activities and business. Evidence base: Phone conversation with Gregory Gerdel, Chief of Research and Operations for Vermont Tourism and Marketing on October 29, 2013; observed temperature and precipitation trends by (i) the National Weather Service (Burlington, Vermont) and (ii) Betts et al. (2011a, b). Remaining Uncertainties: Summer vacationers have many options besides Vermont and their behavior is difficult to predict. The overall health of the US economy over the medium term is also uncertain; future downturns could be positive or negative for summer tourism in Vermont. Summertime pests have increased dramatically in recent years but it is not clear (i) if these increases will continue (or if incidence rates will stabilize) and (ii) how this may affect tourism and recreation revenues. Assessment of confidence based on evidence: **Very High**

Key Message 6	Hotter weather with more severe rain events may dampen recreation and tourism activities slightly, but Vermont's State Parks expect more visitors as a result of climate change, not less. Evidence base: Phone conversation with Greg Whipple, Director of Vermont State Parks, on October 17, 2013. Observed temperature and precipitation trends by (i) the National Weather Service (Burlington, Vermont) and (ii) Betts et al. (2011a, b) Remaining Uncertainties: Similar to Key Message 5, summer vacationers have many options besides Vermont and their behavior is difficult to predict. Their behavior is also linked to weather and climate conditions in their home states; increased summer temperatures in the metro New York City area may drive more tourists north to Vermont irrespective of increased rainfall patterns. The overall health of the US economy over the medium term is also uncertain; future downturns could be positive or negative for summer tourism in Vermont. Assessment of confidence based on evidence: **High**
Key Message 7	Water-based recreation (boating, fishing, swimming) may suffer from higher water temperatures, which can increase algal blooms in lakes and hinder growth of cold-water fish (e.g. trout). On the other hand, warmer waters may improve and lengthen tourists' summer experience in Vermont's lakes. Evidence base: Phone conversation with Greg Whipple, Director of Vermont State Parks, on October 17, 2013. Observed temperature and precipitation trends by (i) the National Weather Service (Burlington, Vermont) and (ii) Betts et al. (2011a, b) Remaining Uncertainties: Algal blooms are closely linked to nutrient run-off. Numerous efforts are underway to reduce this run-off, particularly in collaboration with Vermont's agricultural industries. If this run-off is indeed reduced then increased water temperatures may not result in such blooms and there would be less negative impact on water-based tourism and recreation. Assessment of confidence based on evidence: **High**
Key Message 8	Increased temperatures will encourage expansion of pest species (e.g. ticks and mosquitos), reducing the quality of the recreation experience. Evidence base: Observed temperature and precipitation trends by (i) the National Weather Service (Burlington, Vermont) and (ii) Betts et al. (2011a, b)

	Remaining Uncertainties: Summertime pests have increased dramatically in recent years but it is not clear (i) if these increases will continue (or if incidence rates will stabilize) and (ii) how this may affect future tourism and recreation revenues. Assessment of confidence based on evidence: **High**
Key Message 9	The Fall foliage season may last a little longer as leaves remain on the trees longer due to warmer temperatures. Higher temperatures may also increase the attractiveness of the foliage season for tourists, particularly those from southern climates, which would be positive for tourism. Evidence base: Observed temperature and precipitation trends by (i) the National Weather Service (Burlington, Vermont) and (ii) Betts et al. (2011a, b) Remaining Uncertainties: As the baby boomers age and enter retirement the Fall foliage season and harvest-time may become more popular for tourists but this is not certain. Later frosts could also reduce the intensity of the Fall foliage colors, which could diminish the attractiveness of foliage-based tourism. Assessment of confidence based on evidence: **Medium**
Key Message 10	Warmer temperatures will extend the fall recreation season for hiking, biking, boating, camping and hunting, which will have a positive effect on tourism. Evidence base: Phone conversation with Gregory Gerdel, Chief of Research and Operations for Vermont Tourism and Marketing on October 29, 2013; phone conversation with Greg Whipple, Director of Vermont State Parks, on October 17, 2013. Observed temperature and precipitation trends by (i) the National Weather Service (Burlington, Vermont) and (ii) Betts et al. (2011a, b) Remaining Uncertainties: Similar to Key Message 9, demographic shifts may favor Fall recreation and tourism, as “baby boomers/empty nesters” are no longer constricted by the academic school calendar to determine their vacation times and as the increased number of retirees enables more year-round tourism and recreation demand. Whether this increased demand benefits Vermont or not depends on many variables, some beyond the control of Vermont’s tourism and recreation industries. Assessment of confidence based on evidence: **Very High**

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**

Strong evidence (established theory, multiple sources, consistent results, well-documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Chapter 9: Climate Change Health Impacts In Vermont

Note: Some information and sources adapted from the Vermont Department of Health white paper, *Vermont Climate Change Health Effects Adaptation (Karlsson, 2011).*

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Key Messages:

- **The risk of injuries, illnesses, and deaths related to extreme heat and weather events may increase as these events become more frequent**
- **The burden of infectious diseases may increase due to changes in vector and zoonotic biology as well as changes in water and food contamination**
- **Allergy and respiratory symptoms may increase in relation to increasing plant and mold allergens and irritants in air**
- **Nutritious and sufficient food could be threatened related to food production changes in response to climate change**

1. Introduction

As Vermont's climate changes, a variety of potential health impacts have begun to arise. Some portions of the State's population are more vulnerable than others — children, the elderly, and people who are immune-compromised or who have pre- existing medical conditions or disabilities (IWGCCH, 2010). Lower socioeconomic groups are less likely to have the means to adapt or afford proper healthcare and therefore may also be more vulnerable (IWGCCH, 2010). This raises concerns about climate change's potential effect on health disparities in Vermont (Frosch, 2009). Workers in agriculture, tourism, manufacturing, construction, metallurgy, and athletics may also experience a disproportionately high amount of effects.

2. Extreme Heat Events

Extreme heat events will increase due to increasing temperature (Hayhoe, 2010). Extreme heat will likely lead to heat stroke, heat cramps, heat fainting, heat exhaustion, as well as death (Patz, 2000). Extreme heat can also exacerbate respiratory and cardiovascular diseases such as asthma attacks, heart attacks, and stroke (IWGCCH, 2010). In 2010, 11% of adult Vermonters reported having current asthma and 17% of adult Vermonters reported being diagnosed with asthma at some point in their lifetime. Approximately 55,000 adult Vermonters had asthma in 2010. In 2010, one in 10 children in Vermont had current asthma (VDH Asthma Data Pages 2010). Vermont's asthma prevalence among adults has been statistically significantly higher ($p>0.05$) than asthma prevalence among adults for the entire US population (VDH Asthma Data Pages 2010).

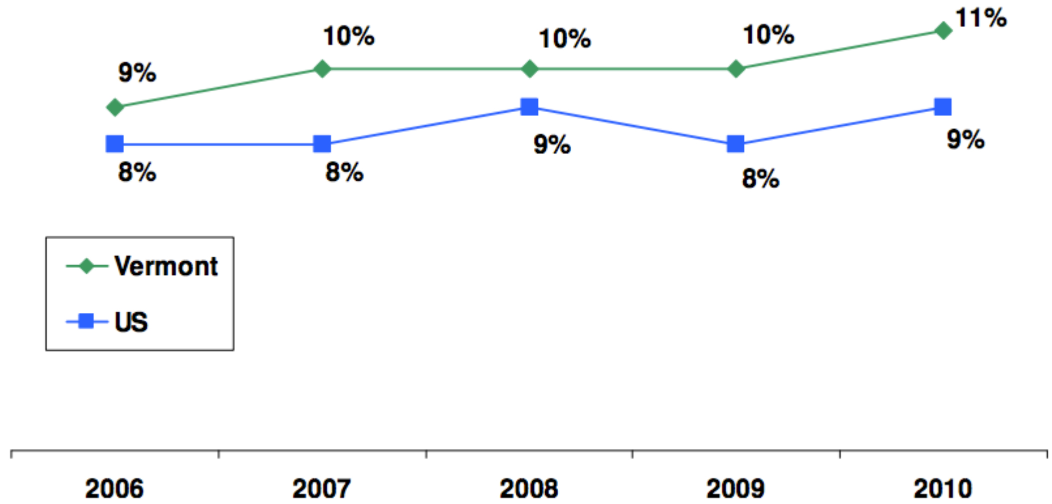


Figure 9.1. *Asthma Prevalence Among Adults. (VDH Asthma Data Pages 2010).*

3. Extreme Weather Events

Extreme weather events from precipitation variability will increase (Patz, 2000). This includes heavy rainfall events (defined as >2 inches in 48 hours) (UCS, 2006), floods (Betts, 2011, ice storms (Keim & Rock, 2002), winter storms (Keim & Rock, 2002), and wildfires. Extreme weather events have the potential to affect human health in a variety of ways from physical harm and injuries to illness and disease. Extreme weather precipitation events will likely cause injury, drowning, and death (Frumkin, 2008, Patz, 2000). Heavy rainfall and floods as well as short term dry spells can lead to water and food borne infectious diseases (Frumkin, 2008). Wildfires can cause and agitate respiratory diseases (IWGCCH, 2010).

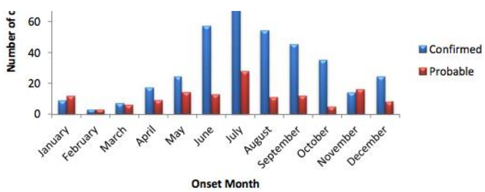
4. UV Radiation and Ozone Depletion

Exposure to UV radiation from ozone depletion may increase in duration and intensity (IWGCCH, 2010). This may lead to an increase in skin cancers (squamous, basal, melanoma) as well as cataracts (IWGCCH, 2010). Melanoma is the fifth most common cancer among Vermonters, and between 2006 and 2007 there were approximately 26 deaths a year (Schafrick, 2013). Bennington, Vermont currently has the highest rate of melanoma.

There is a strong correlation between increasing per capita income and melanoma incidence (Schafrick, 2013). Research is still underway but the increasing wealth could mean an increase in outdoor recreation.

5. Vector-borne and Zoonotic Infectious Diseases

Figure 9.2 *Cases of Lyme Disease in 2012 in Vermont (VDH Lyme Disease Surveillance Report 2012).*



Some tick, mosquito, and rodent vector-borne and zoonotic infectious diseases will increase in transmission (Patz, 2000) due to increasing contact with humans and biting frequency. Expanding geographic ranges, shortening incubation periods and better winter survival from increasing temperature all serve to increase tick and mosquito (and to a lesser extent, rodent) populations. Increasing precipitation may increase mosquito breeding grounds and rodent food supply (Patz, 2000). Drought conditions may cause an increase in mosquito breeding as well by turning rivers into breeding grounds (Patz, 2000). Increased and more resilient tick and mosquito populations will lead to an increase in Lyme disease (Frumhoff, 2007) and West Nile Virus (Soverow, 2009). Increased rodent populations can increase rodent urine, fecal, and saliva-related asthma and viral diseases (Patz, 2000) as well as hanta virus (Patz, 2000).

The number of confirmed and probable reported human cases of Lyme disease in Vermont climbed from 105 cases in 2006 to 623 cases in 2011. In 2012, however, the number of confirmed and probable human cases slightly decreased to 522 cases (VDH Lyme Disease Surveillance Report 2012).

Vermont's northern neighbor, Quebec, began to quantify climate change health impacts. In 2012, West Nile Virus cases tripled, and mortality rates as a result of the disease have been steadily increasing for two decades (Fortin, 2013). Lyme disease became noticeable in Quebec in 2003 and has since increased rapidly with 42 cases in 2012 and 71 in 2013 (Fortin, 2013). Ticks have been observed all over Canada and though the rate of Lyme infection has yet to increase, it is expected to do so (Fortin, 2013).

6. Variation of Seasonal Water Quality and Quantity

Seasonal water quality and quantity variation will increase due to increasing water temperature, increasing precipitation and runoff, as well as short term dry spells (Patz, 2000; UCS, 2006). Drinking contaminated water or eating produce irrigated or processed with contaminated water can cause water-borne microbiologic gastrointestinal diseases from viruses, bacteria, and protozoa including *Cryptosporidium parvum*, *Giardia lamblia, Esecherichia coli,* and other fecal coliform bacteria. Also, eating seafood (especially shellfish) from contaminated water can cause rare food poisoning from *Vibrio vulnificus* (Patz, 2000). Contact with or ingestion of contaminated water can lead to blue-green algae bloom-related hepatotoxin and neurotoxin poisoning (Patz, 2000). Contaminated water can also trigger cases of *Legionella*, which experienced a 217 % increase from 2000 to 2009 in the US (Whitney, 2013). Research is still underway but current hypotheses suspect increased *Legionella* rates are related to unusual weather from this past summer (Whitney, 2013). In the Netherlands and Philadelphia researchers have found similar cases and potential connections between weather and *Legionella* instances (Whitney, 2013). Additionally, researchers have found a link between cloud cover and onset the disease, that is peak cases have been observed during sustained cloud cover. This could be due to moisture trapped by low cloud cover causing an increase in outbreaks (Whitney, 2013).

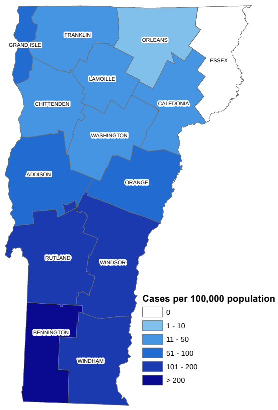


Figure 9.3 *Lyme Disease in Vermont 2012: Incidence rate of confirmed and probable cases (VDH Lyme Disease Surveillance Report 2012).*

7. Food Production and Quality

Changing environmental conditions and water availability will cause disruptions in both food production and quality (IWGCCH, 2010). Chemicals, biotoxins, and pathogenic microbes can lead to seafood contamination (IWGCCH, 2010). Changing use of pesticides in response to changing pest type and distribution may lead to an increase in crop contamination (IWGCCH, 2010). Food-borne illness may increase due to increasing temperature, including food poisoning, *campylobacteriosis* and *salmonellosis* (IWGCCH, 2010). Impaired crop growth or changing agricultural practices of production in other U.S. states can cause sub-optimal nutrition and staple crop shortages (such as corn or soy) in Vermont, where we depend on fresh foods and fodder from other states (IWGCCH, 2010). Changes in material and pesticide use in response to climate changes may also be linked to unknown development, neurologic, or cancer effects (IWGCCH, 2010).

8. Increasing aero-allergens, other allergens, and irritants

Pollen levels will increase due to longer growing seasons or changing geographic distribution of plant species (Patz, 2000; IWGCCH, 2010). Dust will increase with short term dry spells (IWGCCH, 2010), and increasing precipitation and temperature will lead to an increase in mold and mold spores (IWGCCH, 2010).

9. Adaptation

The Vermont Department of Health is already engaged in efforts to adapt to the negative health effects of climate change. These efforts and protocol range from anticipatory and preventative measures to inherently reactive ones. The Vermont Department of Health has put in place early warning protocols to communicate health alerts to the public as well as developing a Health Alert Network to communicate health alerts to healthcare providers and responders. These serve as a general response to all the previous categories of impacts.

9.1 Adaptation to Extreme Heat and Weather Events

The Environmental Public Health Tracking Program provides a record of heart attacks. State-developed reaction protocols relevant to the projected health impacts of climate change in State plans include: The All-Hazards Emergency Preparedness Plan, Emergency Operations Plan (Health

Operations Center), Emergency Medical Services (EMS) System, Vermont Emergency Response Volunteers (VERV), and Epidemiology All-Hazards Plan.

9.2 Adaptation to UV Radiation and Ozone Depletion

The state of Vermont has a State Cancer Plan for education on sun protection developed with funding from the Center for Disease Control's Comprehensive Cancer Control nationwide initiative. Vermont also has a cancer registry.

9.3 Adaptation to Vector-borne and Zoonotic Infectious Disease

Public education efforts aim to alert people to the nature and danger of vector borne diseases. The central dead bird reporting line provides a monitoring system for West Nile Virus, and a Sentinel non-human host surveillance deer sera survey provides information on the mosquito-borne Eastern Equine Encephalitis Virus. There is also a reportable diseases surveillance in place and a monthly infectious disease bulletin that provides brief and timely updates about issues of concern in infectious disease epidemiology by the CDC. Vermont is part of the National Electronic Disease Surveillance System. An Early Aberration Reporting System (EARS) reports automated syndrome-sorted data every 24 hours from seven hospitals to the Vermont Department of Health.

9.4 Adaptation to Variation of Seasonal Water Quality and Quantity

The State has published guidelines for water testing. Water test kits are available for purchase for laboratory testing of private water. A Drinking Water Program with an 800 line offers technical advice on protective technologies for microbial or chemical treatments and on interpretation of water test results. Town Health Officers respond to water quality complaints and provide general surveillance and management of water quality in populated areas. In addition to this there is a blue-green algae reporting line and email. The reportable diseases surveillance program is relevant to this impact as well. So is the Early Aberration Reporting System (EARS).

9.5 Adaptation to Aero-allergen and other Allergens and Irritants

The Vermont Asthma program conducts surveillance of asthma in the state. Town Health Officers can provide some public education and management of allergens and irritants.

9.6 Adaptation to Food production and Quality Disruption

The Food and Lodging Program's sanitarain inspection and the Shellfish Sanitation Program both provide regulation. The reportable diseases surveillance assists in detection of quality disruptions. The Food and Lodging Program has complaint, outbreak, and recall protocols regarding infectious disease epidemiology. The program also has a sanitarian emergency response plan in place. Vermont's Birth Defect Registry is the only passive surveillance mechanism relevant to detecting unknown development effects.

10. Summary Table Rating Quality of Information

Key Message 1	The risk of injuries, illnesses, and deaths related to extreme heat and weather events may increase as these events become more frequent. **Evidence Base:** Hayhoe, K., 2008 Patz, J.A., 2000. IWGCCH, 2010. *Asthma Data Pages* VDH 2010. Patz, J.A., 2000. Frumlin, H., 2008. Keim, B., 2002. Assessment of Confidence Based on Evidence: **Very High**
Key Message 2	The burden of infectious diseases may increase due to changes in vector and zoonotic biology as well as changes in water and food contamination. **Evidence Base**: IWGCCH, 2010. Patz, 2000. Frumhoff, 2007. Soverow, 2007. VDH Lyme Disease Surveillance Report 2012. Fortin, 2013. UCS, 2006. Whitney, 2013. Assessment of Confidence Based on Evidence: **Very High**
Key Message 3	Allergy and respiratory symptoms may increase in relation to increasing plant and mold allergens and irritants in air. **Evidence Base:** Patz, 2000. IWGCCH, 2010. Assessment of Confidence Based on Evidence: **High**
Key Message 4	Nutritious and sufficient food could be threatened related to food production changes in response to climate change **Evidence Base:** IWGCCH, 2010. Assessment of Confidence Based on Evidence: **High**

Confidence Level			
Very High	High	Medium	Low

Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Chapter 10: Transportation

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Key Message

Increases in average annual temperatures, more frequent heat waves, less snow, more rain, and shorter winters have been experienced across the Northeast since the 1970's (Wake, 2005; Frumhoff et al., 2008), and specifically reported in Vermont (Stagger and Thill, 2010; Betts, 2011). There is sufficient evidence to suggest these climatic trends will continue through the next century, having negative consequences for Vermont's transportation infrastructure.

1. Description of Evidence Base

In 2008, the Transportation Research Board of the National Academy of Science issued Special Report 290, "The Potential Impact of Climate Change on US Transportation" (TRB, 2008), which concluded every mode of transportation in every region will be impacted. This report influenced VTrans' *Climate Action Plan* (VTrans, 2008), which calls for collaboration between climate scientists, state officials, and universities in adaptive transportation planning. This issue has also been a topic in the Vermont Climate Adaptation White Paper Series and the focus of several scholarly articles. The main climate trends that will impact Vermont's road, highway, and rail infrastructure are detailed below.

1.1. More frequent extreme heat days:

More days above 90°F will lead to premature deterioration or failure of infrastructure, including more rapidly degraded pavement, deformed rail lines, and damaged bridge joints, all of which will result in higher maintenance costs (Jollands et al., 2007; TRB, 2008; VTrans, 2008; Peterson et al., 2008; Jaroszweski et al., 2010; Oven et al., 2012; Oslakovic et al., 2012; Chinowsky, 2013; Ebersole, 2013). Periods of extreme heat could also cause increased incidents of vehicle overheating and tire deterioration. Finally, limitations to work days over concerns of worker safety may also become increasingly commonplace (Jollands et al., 2007; TRB, 2008; VTrans, 2008; Peterson et al., 2008; Oslakovic et al., 2012).

1.2. Greater variability of daily temperatures:

Changes in the range of maximum and minimum temperatures will cause an elevated frequency of freeze-thaw cycles in winter months, creating more potholes, deteriorated culverts, frost heaves, and weakened bridge expansions joints (TRB, 2008; VTrans, 2008; Ebersole, 2013).

1.3. Greater precipitation and more extreme weather events.

Greater rainfall will cause increased flooding, mudslide, and runoff damage to low lying roads, culverts, bridges, railroads, and other infrastructure (Jollands et al., 2007; Larsen et al., 2008; Peterson et al., 2008; TRB, 2008; VTrans, 2008; Jaroszweski et al., 2010; Oslakovic, 2012; Oven et al., 2012; Erbesole, 2013). Tropical storms reaching Vermont are expected to become more common (VTrans, 2008; Betts, 2011), with more severe flooding in the Champlain Basin, where water levels on Lake Champlain could stand as much as 1-2 ft. higher by 2100 (Stagger and Thill, 2010). Storm events will also cause weather related traffic disruptions and transit delays, and possibly necessitate evacuations during extreme events (Suarez et al., 2005; TRB, 2008; VTrans, 2008).

1.4. More winter precipitation as rain.

When precipitation falls as rain in winter months instead of snow, it leads to immediate runoff and increases the risk of floods, landslides, slope failures, and consequential damage to road and rail, especially in rural areas (UCS, 2007; TRB, 2008; VTrans, 2008; Ebersole, 2013). Elevated soil moisture could also damage roads, bridges, and tunnels. (du Vair et al., 2002; TRB, 2008; Ebersole, 2013).

2. New Information and Remaining Uncertainties:

While there is sufficient evidence of climate change and models to assess how this will impact future weather conditions in the Northeast, more research is needed to better understand Vermont's climate trends and projections. This inadequacy was addressed in VTrans' *Climate Action Plan*. Although some statewide research has been conducted at the state level since 2008, including the Nature Conservancy's 2010 report: *Climate Change in the Champlain Basin* (Stagger and Thill, 2010), policy makers continue to seek further supporting evidence. The *Climate Action Plan* also stressed the need to inventory critical transportation infrastructure to identify locations, weather conditions, and time frames in which projected changes might be consequential.

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Chapter 11: Climate Change Education and Outreach

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Key Messages

- **Over the past 15 years the Vermont State Government, and in particular the current Governor's Office, has taken a lead role in encouraging education and outreach with respect to climate change, in part through the 2012 Executive Order establishing the Climate Change Cabinet that *inter alia* defines broad responsibilities for increasing public awareness of climate change issues.**
- **Vermont's institutions of higher education are also playing lead roles in conducting research and disseminating knowledge to both the scientific community and the public at large regarding climate change in Vermont and at national and global scales.**
- **The study of climate change is only partially, but increasingly, incorporated into K-12 education programs throughout the state. Student knowledge of earth science lags behind that of biological and physical science. The Next Generation Science Standards being introduced statewide next year include specific topics on energy, weather, climate and human sustainability.**
- **Informal climate change education and outreach is offered by a wide range of non-profit organizations, citizens groups and town energy committees, addressing specific issues related to Vermont's lakes and rivers, forests, wildlife, energy generation, etc. covering both adaptation and mitigation.**
- **Despite these efforts and much progress, *there is a long way to go* in the use of education and outreach to help Vermonters mitigate and adapt to climate change through changes in their own behavior (energy usage, consumer behavior, voting patterns, etc.). Combining these education activities with appeals to Vermonters' values, changes in material incentives, and strengthened social norms could induce more pro-environmental behavior.**

1. Introduction

Scientists and social scientists have frequently called for increased public education and outreach to induce people to change their attitudes and behaviors related to climate change. Whether such educational and outreach activities actually do change people's attitudes and behaviors on their own is disputed in the academic literature. Review of the evidence (Gardner and Stern, 1996) does indicate, however, that when education and outreach activities are combined with appeals to values, changes in material incentives, and strengthened social norms, pro-environmental behavior can be induced.

Concerning the link between education and attitudes, Heberlein (2012) argues that attitudes only change over long time periods and as a result of direct experience and changes in people's roles and identities, not as a result of education and outreach. On the other hand, Zsoka et al (2013) argue there is a strong correlation between environmental education and knowledge, which in turn shapes attitudes about sustainable consumption.

With regards to the links between attitudes and behavior, Rodriguez-Barreiro et al (2013) present evidence showing a causal relationship connecting attitudes with pro-environmental behavior. In addition, Best and Kneip (2011) provide some evidence that environmental attitudes affect environmental behavior, and Erickson (2010) found peer-to-peer education to be quite effective at improving environmental behavior. Gadenne et al (2011) also found there was a strong association between environmental attitudes and energy-saving behaviors. On the other hand, Martinsson et al (2011) found that socio-economic factors had a greater impact on energy-saving behavior than environmental attitudes.

Significant literature exists on the impacts of education in changing other types of behavior, for example, health-related. One of the cornerstones of this work is the concept of the stages of change and an individual's change readiness. The stages of change include pre-contemplation (no change being considered), contemplation, preparation, action and maintenance (Prochaska, 2001). Change readiness is defined as an individual's "beliefs, attitudes, and intentions regarding the extent to which changes are needed…" (Armenakis et al, 1993). Education and outreach activities related to climate change are thus intended to increase Vermonters' change readiness and to move them along these stages of change. The objective is not just to revise beliefs and attitudes, but also to induce Vermonters to sustainably change their behavior in ways that mitigate and adapt to climate change.

In summary, education and outreach activities may not change environmental attitudes and behaviors in positive ways all by themselves. It is widely accepted that there is little downside to such activities, and that when combined with other interventions (changes in material incentives, strengthened social norms, and appeals to values), they can be effective (Mirosa, 2013; Stern, 2000; Inglehart, 1990). Furthermore, the risks posed by climate change are sufficiently alarming to warrant expanded education and outreach activities, with the hope that they will increasingly affect attitudes and behaviors in the future, particularly as the risks become more apparent and the public's direct experiences of climate change increase.

2. Education and Outreach from Vermont State Government

Over the past 15 years the State of Vermont has taken a lead role in expanding education and outreach with respect to climate change. The Governor's Climate Change Commission noted in 1997 that education and outreach was essential for long-term success of all climate change mitigation activities advanced in the State of Vermont. The subsequent Vermont Climate Collaborative (2008-2011) broadened the discussions between the State, academic institutions and public interest groups. In December 2012 Governor Shumlin signed an Executive Order (No.

15-12) establishing a Climate Change Cabinet which has as one of its many responsibilities improving "the understanding of the effects of climate change in Vermont" and provision of "information to Vermonters on all matters relating to a changing Vermont climate, including what to expect in the coming years and actions citizens can take to reduce their emissions of greenhouse gases". Another task of the climate change team is to "continue public outreach to explain climate changes, impact on our future environment, and actions that can be taken to reduce an individual's and business's carbon footprint".

There are many activities underway. Just to cite a few, a quarterly Climate Change Newsletter is published, covering a wide variety of climate change issues including community impact, climate change policy formulation, emerging science of climate change and new technologies to help Vermonters mitigate and adapt to climate change. In addition, the State has produced a high-quality 12-minute educational video explaining the basics of climate change science, the potential effects on Vermont and actions to take. Among many other excellent reports, the State recently published a Climate Change Adaptation Framework, focused on Vermont's natural resources and the services they provide.[9] In summary, unlike some other states, Vermont's politicians and policymakers from both parties have acknowledged climate change science and the need to develop informed policies and programs designed to mitigate and adapt to climate change.

3. Higher Education

Vermont's institutions of higher education have also taken a lead role in researching and disseminating knowledge with respect to climate change, both present and future. For example, the University of Vermont (UVM) was among the very first to emphasize issues of environmental sustainability, with the creation of the Environmental Studies program more than 30 years ago. Today, led by the Rubenstein School of Environment and Natural Resources, the Gund Institute of Ecological Economics, and other schools of science and applied economics, UVM is recognized nationally for its work on climate change. In addition, the Vermont State Climatology Office is housed at UVM's Department of Geography, providing a wide range of climate information to Vermonters, while UVM's Research on Adaptation to Climate Change (RACC) conducts trans-disciplinary research that integrates the interactions of climate, environment, society and land use policy. There are many more examples of UVM's pro-active engagement in conducting education and outreach on climate change issues, which can be found easily on UVM's website (www.uvm.edu).

Many other state and private colleges in Vermont have initiated research and education programs related to climate change. For example, in 1965 Middlebury College became the first

[9] Many more education and outreach activities can be found on the State's website: http://www.anr.state.vt.us/anr/climatechange.

college in the nation to establish an environmental studies major, which now includes a focus on climate change, and in 2007 pledged to become carbon neutral (not yet achieved). It has conducted repeated faculty research symposiums on climate change and in 2013 began a community outreach program to increase awareness of climate change issues among Vermonters. Middlebury has also expanded its own use of biomass and bio-methane for heat and energy generation, providing opportunities for ongoing research and education regarding renewable energy generation and climate change mitigation. This led to Middlebury being awarded the Climate Leadership Award in 2013 by Second Nature, a Boston-based national nonprofit that works with college and university leaders to incorporate sustainability in all aspects of higher education, from academics to operations.[10] For its part, Bennington College was recognized in 2013 for achieving the highest energy savings of any college or university participating in Efficiency Vermont's two-year Energy Leadership Challenge.[11] Textbox 11.1 below offers a case study of the efforts of Green Mountain College to mitigate and adapt to climate change, arguably leading the way in expanding education and outreach among all higher education institutions nationwide.

Box 11.1: Case Study of Green Mountain College: Green Mountain College (GMC) in Poultney, VT has made Environmental Sustainability its core educational mission. Every student enrolled is required to complete a 37-credit Environmental Liberal Arts General Education program. Students have additional opportunities to combine service learning with sustainability, participate in "eco-leagues" and acquire hands-on experience on working farms.

In 2011 GMC became the first college in the United States to achieve carbon neutrality by investing in energy efficiency, adoption of clean renewable energy and purchase of quantifiable local carbon offsets. GMC has a biomass plant that burns locally sourced wood chips to heat 85% and power 20% of the campus' two dozen buildings, and has sourced 1.2 million KwH per year of bio-methane from cows since 2006. Going further, GMC has committed itself to meeting 100% of its energy needs through renewable sources by 2020. Consistent with its mission, GMC voted in 2013 to divest all of its investment holdings in fossil fuel-based companies. GMC is nationally recognized for its leadership in environmental sustainability at the higher education level, and earned a perfect score of 99 for environmentalism in Princeton Education Review's Guide to Top Colleges for 2014.

Source: www.greenmtn.edu

4. K-12 Education and Outreach

The State promotes a wide range of environmental education programs for K-12 education, many of them linked to climate change issues. For instance, the Vermont Energy Education Program (www.veep.org) provides training and curriculum materials for Vermont teachers on topics of energy efficiency, renewable energy and conventional energy sources. In 2013 VEEP reached

[10] http://www.middlebury.edu/sustainability/node/451698

[11] http://www.bennington.edu/newsevents/newsfullstory/13-10-21/Bennington_Honored_for_Sustainability_Practices.aspx

more than 3,600 teachers and students in 60 schools (out of a total of 360) around the state, covering about 5% of all Vermont students. VEEP works with a national program, the Alliance for Climate Education, which has also done several "assemblies" to educate Vermont schoolchildren about climate change. There are additional national providers of climate change curriculum (e.g. KidWind, NEED and Resource Action Program), but it is not known how many Vermont teachers are using this in their classrooms. Another Vermont-based example of climate change-related curriculum is the Water Education for Teachers (WET) project (www.projectwet.org), an interdisciplinary K-12 program designed to facilitate and promote awareness, appreciation, knowledge and stewardship of Vermont's water resources, which includes a 500+ page curriculum and activity guide for teachers[12].

But what do Vermont students actually know about climate change? If student learning about Earth and Space Science is roughly equivalent to their knowledge of climate change, than the results of the 2013 statewide science assessment (New England Common Assessment Program, or NECAP) suggest that *Vermont students do not know enough*. The NECAP results showed:

- In Grade 4, Earth/Space Science scores lagged 11 percentage points behind scores for Physical Science and 5 percentage points behind Life Science scores;
- In Grade 8, Earth/Space Science scores lagged 4 percentage points behind scores for Physical Science and 4 percentage points behind Life Science scores; and
- In Grade 11, Earth/Space Science scores exceeded Physical Science scores by 1 percentage point and were equal to Life Science scores.

At the very least, these NECAP results indicate that Vermont students know less about climate change than they do about biology, physics or chemistry. Moving beyond factual knowledge to understanding issues surrounding climate change (which is more complex), we can assume the situation is even less positive. For example, understanding climate change would typically involve being able to analyze data and use evidence to support a claim or prediction. Students' ability to do this is referred to as "inquiry thinking". On the 2013 NECAP science assessment, Grade 4 students scored just 29%; Grade 8 students scored 36% and Grade 11 students scored 39%. These are not encouraging results.

On a more positive note, many Vermont schools have included the study of global and local climate change as part of their regular science and social sciences curricula, which is offered at a wide range of grades depending on the school district. Furthermore, this progress is set to become universal with the implementation statewide of the Next Generation Science Standards in academic year 2014-2015, which includes specific topics regarding energy, weather, climate and human sustainability.[13] The Vermont Department of Education and the many teachers who have collaborated with the Department to develop these new standards should be commended

[12] (For more information, refer to: www.anr.state.vt.us/site/html/.../climatechangecurriculummaterialslinks.pdf)

[13] See for example: http://www.nextgenscience.org/hsess-wc-weather-climate

for their excellent work. The case study in Textbox 11.2 below describes one school's extremely innovative and exciting effort related to sustainability.

Box 11.2: Case Study of The Sustainability Academy, at Lawrence Barnes Elementary School, Burlington, Vermont

The Sustainability Academy is the first sustainability-themed public elementary school in the United States. In this case, sustainability is defined as "the shared responsibility for improving the quality of life for all – economically, socially and environmentally – now and for future generations". The school aims to integrate the concepts of sustainability into all aspects of the K-5 school, from the curriculum to campus practices. Every unit of study in all grades integrates the three pillars of sustainability: economic, equity and environmental, and all grades practice place-based education, service learning and project-based learning. The school's success in this regard led to a recent article published in *The Atlantic* magazine (October 9, 2013).[14]

The "big ideas" for sustainability, which the school strives to embrace and teach and which relate perfectly to climate change, include:

- Community	- Systems	- Diversity	- Interdependence
- Cycles	- Change over time	- Limits	- Fairness/Equity
- Place	- Ability to make a difference		- Long-term effects
- Equilibrium			

A wide range of community partners further enrich the learning experiences for students, enabling outdoor education, renewable energy projects, Farm-to-School food programs emphasizing locally-grown good, and other experiential programs. Shelburne Farms, a non-profit environmental education center, is the core partner, along with private sector partners (e.g. Seventh Generation, The Alpine Ski Shop), higher education institutions (Champlain College and the University of Vermont), and non-profits such as The Intervale Center, Local Motion, Friends of Burlington Gardens, the Community Sailing Center, the YMCA and ReSource.

Since the Sustainability Academy was launched 5 years ago, the school has turned around from being a "failing" school to a magnet school with a waiting list for entrance into kindergarten. Student attendance and student test scores have improved markedly.

Source: www.sa.bsd.schoolfusion.us

[14] http://theatlantic.com/education/education/archive/2013/10/vermont-report-shaping-the-soul-of-a-school/ downloaded on November 8, 2013.

5. Non-Formal Education and Outreach

There are many community-based committees and non-profit organizations that increase public awareness and action regarding climate change issues. For example, the Vermont Energy and Climate Action Network, VECAN helps communities reduce energy costs and climate impacts through conservation, increased energy efficiency and conversion to renewable energy sources, and offers a web-based portal for information on the 92 statewide community energy committees. Efficiency Vermont, operated by the private non-profit Vermont Energy Investment Corporation, provides technical assistance, rebates, and other financial incentives to help Vermont households and businesses reduce their energy costs with energy-efficient equipment, lighting, and approaches to construction and major renovation. In doing so it increases the public's understanding of the need to reduce the use of fossil fuels that contribute to climate change. The Energy Action Network and Renewable Energy Vermont are two more examples of non-governmental organizations that aim to bring key stakeholders together to mitigate climate change.

The Vermont Natural Resources Council has long been a voice on issues surrounding environmental sustainability, and in 2013 produced an important report entitled, ''Toward a Resilient State". This report explicitly examines how Vermont can both mitigate and adapt to future climate change across a range of areas (energy usage, housing, forests and wildlife, water, etc.), and provides a wide range of perspectives on the issue of resiliency from well-known Vermonters. In addition, VNRC organizes important conferences related to climate change, such as the Community Energy and Climate Action Conference (December 2013). VNRC has also teamed up with Efficiency Vermont to promote home weatherization to reduce heating costs and greenhouse gas emissions, in part through expanded education and outreach activities.

In the for-profit private sector, Green Mountain Power has teamed up with four Rutland county colleges and the University of Vermont to expand education and outreach related to energy innovation,15 and has established the Renewable Education Center as an outdoor education center featuring a fully functional 50 kilowatt solar farm, wind testing tower, educational signs, and a 2 megawatt hydro station.16 Given the very close relationship between expanded use of renewable energy and mitigation of climate change, these activities by non-governmental entities to expand the public's knowledge of climate change issues are quite significant.

More generally, the Vermont Businesses for Social Responsibility promotes the shift away from a fossil-fuel based economy toward one entirely driven by renewable energy. For example, their Business Energy Action program partners with Efficiency Vermont and other agencies to provide technical and financial assistance to businesses to reduce their energy costs, and those businesses that make the most progress receive special publicity and public recognition. Other private sector firms, such as All-Earth Renewables and SunCommon, provide education, training

[15] http://digital.vpr.net/post/green-mountain-power-partners-rutland-colleges-find-future-employees

[16] http://www.greenmountainpower.com/community/programs/renewable-education-center/

and outreach for how to expand renewable energy generation and distribution by both individuals and companies in Vermont.

6. The Media as Partners in Observing and Communicating Climate Change Indicators

Statewide and local media are natural partners in educating the public about localized and regional climate change. The Joe's Pond Ice Out contest is a terrific example of a simple and fun way to encourage discussion of change that Vermont's residents (and out-state-people too) can observe and participate in. The two 2014 winners were from Iowa and Massachusetts.

Local constituencies (which might includ corporate sponsorships tied to media ad buys) might encourage "first snowfall," "last snowfall," "length of maple season," "first hatch" of important insects, etc. A "Busy as the Bees" contest might find sponsorship based around the first siting of honeybees coming out after a long winter in a locale where pollinators play a vital agricultural role. Birders frequently document the first sitings of migrating species — and could be encouraged to share information about highly visible and interesting bird species with local radio or TV stations and small-town newspapers. Comparisons of the recorded dates would only be valid over a significant timeframe, but the contests and discussion could educate the public about the correlation between seasonal changes and long-term climate changes.

This report might stimulate interest in examining localized climate events and recording them at schools — who could provide information over time to local media outlets.

7.Gap Analysis: Additional Education and Outreach Activities needed for Climate Change Mitigation and Adaptation

Despite the many activities described above in expanding education and outreach activities related to climate change, **Vermont still has a long ways to go.** There is a large gap between forward-looking state-wide reports and actual public awareness and action.

In fact, if one accepts that consumer advertising is an effective form of education and outreach, then the overall balance today remains stacked against climate change mitigation and adaptation. The repeated exhortations to consume more stuff, purchase more high gas-consumption vehicles, and buy more high carbon-footprint food, in combination with the explicit denial of the science and facts of climate change in some mass media outlets, slow if not reverse the needed behavioral responses to climate change.

A concrete example of where more education and outreach is needed is in the transportation sector, specifically with a goal of persuading more Vermonters to purchase electric or hybrid vehicles to reduce the negative impact of our driving on climate change. Electrification of Vermont's vehicles is a key element of the state's Comprehensive Energy Action Plan, given that transportation makes up 33% of our total energy usage[17] and 44% of our greenhouse gas emissions[18]. Unfortunately, while registrations of hybrid vehicles grew significantly between 2006-2010, they accounted for just 1% of all vehicles registered (6,335 out of a total of 514,894 vehicles) in 2010.[19] In terms of new car buying in 2010, hybrid vehicles comprised just 4% of new vehicle purchases, indicating limited progress and a long ways to go.

One outreach strategy would be to appeal more to the values Vermonters hold dear[20], such as community, the environment, hard work, self-reliance, small-scale and getting the most out of every dollar. For example, comparing gasoline expenditures over the 100,000-mile life of a car, driving a Prius (49 mpg) would cost $7,142 (at $3.50/gallon) while driving a regular gas-powered vehicle (22 mpg) would cost $15,909, a savings of more than $8,700 for the Prius owner. That's a message that should resonate with frugal Vermonters. Indeed, every one of these Vermont values has a potential positive behavioral application with respect to climate change that could be encouraged through appropriate education and outreach.

8. Conclusion

More education and outreach is needed with respect to the risks posed by climate change for present and future generations of Vermonters, combined with awareness-raising of the potential positive impacts of climate change mitigation and adaptation. Increased governmental and non-governmental outreach, formal and non-formal education, public service advertising, private sector corporate social responsibility and social marketing programs, etc., are all required to induce the behavioral changes required. Particularly if education and outreach activities are combined with material incentives and strengthened social norms for pro-environmental behavior, real progress could be made in helping Vermonters mitigate and adapt to climate change.

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[17] http:// www.publicservice.vermont.gov/ downloaded on November 2, 2013.

[18] Vermont Agency for Natural Resources, 2007

[19] The Vermont Transportation Energy Report: Vermont Clean Cities Coalition, August 2010; and The Vermont Transportation and Energy Report, 2011.

[20] These values are eloquently captured in the Council of the Future of Vermont's 2009 publication, "Imagining Vermont: Values and Vision for the Future", produced by the Vermont Council on Rural Development.

9. Summary Table rating quality of information

Key Message 1	The Vermont State Government over the past 15 years, and in particular the current Governor's Office, has taken a lead role in encouraging education and outreach with respect to climate change, in part through the Executive Order establishing the Climate Change Cabinet that defines broad responsibilities for increasing public awareness of climate change issues. **Evidence Base:** www.anr.state.**vt**.us/anr/**climatechange/ClimateCabinet**.html; Vermont Climate Collaborative (www.uvm.edu/~vtcc/); **Remaining Uncertainties:** Effective education and outreach requires Executive and Legislative branch coordination on climate change issues, which is not certain. The Legislature's willingness to commit necessary public funds to support increased energy efficiency has yet to be demonstrated. In addition, it is not clear how the Legislature will respond to the policy recommendations provided in the 2013 Renewable Energy Siting Commission report. Both of these measures include education and outreach components. **Assessment of Confidence Based on Evidence: Very High**
Key Message 2	Vermont's institutions of higher education have also played lead roles in conducting research and disseminating knowledge to both the scientific community and the public regarding climate change in Vermont and at national and global scales. **Evidence Base:** Reports and studies downloaded from websites managed by UVM, Green Mountain College, Middlebury College, Castleton State College, Johnson State College, Bennington College and others. **Remaining Uncertainties:** Information has not been gathered, much less analyzed, from all of Vermont's higher education institutions. It is possible that the colleges not covered by this chapter are far less active in conducting education and outreach related to climate change, which would reduce the overall role played by higher education in expanding public knowledge and awareness of this issue. **Assessment of Confidence Based on Evidence: Very High**
Key Message 3	The study of climate change is only partially, but increasingly, incorporated into K-12 education programs throughout the state. Student knowledge of earth science lags behind that of biological and physical science. The Next Generation Science Standards being introduced statewide next year include specific topics on energy, weather, climate and human sustainability.

	Evidence Base: http://www.nextgenscience.org/vermont; www.veep.org; www.anr.state.**vt**.us/site/html/.../**climatechange**curriculummaterialslinks.pdf; www.projectwet.org; NECAP science results for 2013 provided by VT Department of Education. **Remaining Uncertainties:** Because of resource constraints, there is limited data gathering by the state regarding actual integration of climate change issues into science and social science curricula. Available information is largely anecdotal. Vermont teachers' acceptance and integration of the Next Generation Science Standards (along with the broader Common Core Curriculum) is not certain, and will take considerable time to implement in any case. As**sessment of Confidence Based on Evidence: High**
Key Message 4	Non-formal climate change education and outreach is offered by a wide variety of community-based committees and non-profit organizations, addressing specific issues related to Vermont's lakes and rivers, forests, wildlife and energy generation, covering both adaptation and mitigation. **Evidence Base:** www.vecan.net; www.efficiencyvermont.com; www.eanvt.org; www.revermont.org; www.greenmountainpower.com; www.vnrc.org **Remaining Uncertainties**: While the activity and quality of Vermont's non-governmental organizations working on climate change-related issues is exemplary, the actual level of awareness about climate change among adult Vermonters is unknown. Including a few questions to address this issue in the annual Vermonters Poll conducted by the Center for Rural Studies at UVM would be illuminating. **Assessment of Confidence Based on Evidence: Very High**
Key Message 5	Despite these efforts and much progress, there is a long way to go in the use of education and outreach to help Vermonters mitigate and adapt to climate change through changes in their own behavior (energy usage, consumer behavior, voting patterns, etc.). Increased focus on Vermonters' values and how climate change may affect both present and future generations could be helpful. **Evidence Base:** www.publicservice.vermont.gov; The Vermont Transportation Energy Report: Vermont Clean Cities Coalition, August 2010; Council of the Future of Vermont's 2009 publication, "Imagining Vermont: Values and Vision for the Future", produced by the Vermont Council on Rural Development. **Remaining Uncertainties:** Whether education and outreach activities can actually include positive behavior with respect to climate change on their own is uncertain and widely debated in the literature. Given the likelihood of increased extreme

	weather events related to climate change and people's perceptions of the associated risks, such activities should become more effective over time but this is conjectural. **Assessment of Confidence Based on Evidence: High**

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well-documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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***Appendix A**. Vermont weather stations used for climate analysis in this report. All data from NOAA/NWS 2014 (See Chapter 1).*

Name (Station ID)	County	Station	Lon	Lat	Elevation	Active?	Begin Year	High/Low land
Jay Peak (JAYV1)	Orleans	43-4189	-72.50	44.94	1840	Y	1988	H
Mount Mansfield (MMNV1)	Lamoille	43-5416	-72.82	44.53	3950	Y	1954	H
Peru (PERUV1)	Bennington	43-6335	-72.9	43.27	1700	Y	1940	H
South Lincoln (SLNV1)	Addison	43-7612	-72.97	44.07	1341	Y	1981	H
Burlington Int'l Airport (KBTV)	Chittenden	43-1081	-73.15	44.47	330	Y	1940	L
Cornwall (CWLV1)	Addison	43-1580	-73.21	43.97	345	Y	1893	L
Enosburg Falls (ENOV1)	Franklin	43-2769	-72.81	44.91	420	Y	1891	L
Northfield (NORV1)	Washington	43-5733	-72.66	44.17	670	Y	1887	L
Rutland (RUTV)	Rutland	43-6995	-72.98	43.63	620	Y	1916	L
Saint Johnsbury (SJBV1)	Caledonia	43-7054	-72.02	44.42	700	Y	1894	L
South Hero (SHRV1)	Grand Isle	43-7607	-73.30	44.63	110	Y	1969	L
Woodstock (WDSV1)	Windsor	43-9984	-72.51	43.63	600	Y	1892	L