DRAFT Chittenden County Climate Change Trends and Impacts

02/15/12

An ECOS Analysis Report

This analysis report summarizes for local and regional policy makers how Chittenden County's climate has already changed and how our climate is projected to further change during this century. This report also discusses how these climate changes will impact people, the environment, and our communities.

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ENVIRONMENT | COMMUNITY | OPPORTUNITY | SUSTAINABILITY

A SUSTAINABLE FUTURE FOR CHITTENDEN COUNTY

The Chittenden County Regional Planning Commission prepared this report to provide local and regional policy makers an understanding of how climate change has already affected Chittenden County's climate, what further changes are predicted, and how these changes will impact the region.

This report is intended to be the first phase of a regional climate planning initiative. Subsequent phases will include a regional greenhouse gas inventory and planning for climate change mitigation and adaptation. These efforts are intended to supplement and support CCRPC's ECOS Project and the development of a regional sustainability plan.

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Chittenden County Climate Change Trends and Impacts

AN ECOS ANALYSIS REPORT

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HIGHLIGHTS

Our climate has already changed over the past 50 years and scientists project that these changes will continue and accelerate this century:

- The average annual temperature increased in the latter half of the 20th century; winter temperatures are warmer and summer temperatures are hotter. Temperatures are projected to continue to increase throughout the 21st century, and the number of extreme heat days is expected to increase.
- Lake ice cover has decreased. Lake Champlain freezes over later than it used to, and increasingly doesn't freeze up at all. With the warmer winters projected by climate models, this trend is likely to continue.
- The growing season already starts earlier and lasts longer than it did 50 years ago. Climate models project that lengthening of the growing season will accelerate this century.
- Annual precipitation has already increased, but more falls as rain instead of snow. This trend is expected to continue in this century, with most of the additional precipitation occurring in the winter months.
- Extreme precipitation events are projected to be more frequent and more intense. Nevertheless, short-term drought conditions in summer are projected to be more frequent.
- Overall, Vermont's climate is projected to become more like today's Mid-Atlantic climate.

These changes will have profound impacts on the environment, public health, infrastructure and the economy:

- Ozone levels would likely not comply with national air quality standards.
- High streamflow events will occur more frequently with increased risk of flooding. Peak streamflows will occur 1-2 weeks earlier in the season.
- Summertime low streamflows will be longer and more pronounced.
- Water quality may be impaired by increased stormwater and flooding. Warmer temperatures and nutrient loading may encourage growth of *E. coli* and blue-green algae blooms.

- Aquatic species requiring cold water, such as brook trout, will struggle to survive in warmer waters with less dissolved oxygen, as well as competition from species better adapted to warmer water temperatures.
- Forest communities will gradually shift from maple/beech/birch forest to an oak/hickory forest type that is better adapted to warmer, wetter conditions.
- Extreme heat days and heat waves increase the risk of heat stress in vulnerable populations.
- Warmer temperatures will allow insect-borne diseases to spread. Increased pollen and ozone will aggravate allergies, asthma and other respiratory diseases.
- Increased flooding will threaten homes, businesses and infrastructure.
- Water supplies may be threatened by both flooding and droughts.
- Warmer temperatures may reduce energy demand for winter heating, but will increase summer energy demand for cooling.
- Dairy production and crop yields will likely decline without implementing adaptive measures that may be costly. Maple syrup production will decline due to warmer winter temperatures.
- The cold-dependent winter sport industry will be threatened by warm temperatures and lack of reliable snow and ice cover.

Communities, businesses and individuals can take two types of action to deal with the changes projected in our climate. *Mitigation strategies* include actions that reduce the amount of greenhouse gases emitted or increase the amount of stored carbon in forests. By reducing the amount of carbon that we contribute to the atmosphere, we help lessen the amount of climate change that is occurring. *Adaptation strategies* include actions to offset or adapt to the impacts that will accompany increasing temperatures and greater precipitation. Planning efforts to identify, prioritize and implement mitigation and adaptation strategies are the next steps for Chittenden County.

INTRODUCTION

The ECOS Project Steering committee is a broadly-based 60+ member partnership committee to implement strategies to improve Chittenden County's long-term sustainability: economically, environmentally and socially. The Steering Committee has committed to a five-phase project:

1. Adopt common goal statements
2. Analyze reports regarding economic development, housing, energy, land use and transportation, natural resources and health/human services/education
3. Develop indicators tied to the goal statements
4. Prioritize implementation actions for the next five, ten and twenty years
5. Invest in high priority implementation actions

The results will inform regional, municipal and other plans as they are updated. This report is part of ECOS' Phase Two.

The Chittenden County Regional Planning Commission (CCRPC) is a recipient of a Housing and Urban Development (HUD) Regional Sustainability Grant and is utilizing this opportunity to conduct the ECOS project. The ECOS project's overall goal is to identify and implement strategies that will improve Chittenden County's long-term sustainability. To achieve this, CCRPC has partnered with various regional partners to collect data and conduct analyses to expand information and decision making capacity to better plan for needed housing, economic development, energy, climate change, land use/transportation, and natural resources.

ECOS outcomes are anticipated to reflect this unprecedented cooperation in regional planning and will be incorporated into the Metropolitan Transportation Plan (MTP) and the Chittenden County Regional Plan, as well as other plans, through the prioritization of implementation activities to advance the sustainability of our region. Indicators will be used in the ECOS project to gage the region's progress towards reaching its sustainable development goals into the future. This report, as well as other assessments from the ECOS partners forms the foundation for reaching our shared vision.

This ECOS analysis report summarizes the changes that have already occurred in Chittenden County's climate and the results of model-based research done by other credible entities. Because of the complexity of most climate models and the detailed understanding of climate science required to interpret climate model results, CCRPC has not conducted its own climate modeling. Our survey of climate projection research has focused on studies that specifically address climate projections for the Northeastern United States, New England, Vermont or the Lake Champlain Basin. This report also summarizes the anticipated impacts on the region's resources, economy, infrastructure and people.

UNDERSTANDING CLIMATE CHANGE

Our climate is a result of complex interactions between the atmosphere, oceans, ecosystems and landforms. As far back as can be measured, there have been short-term and long-term climate cycles. Climate changes that led to the extinction of the dinosaurs, or the ice ages, are examples of these climate cycles.

Heat from the sun is naturally trapped by the earth's atmosphere, much the way heat is captured within a greenhouse (Figure 1). Certain gases in the atmosphere, known as greenhouse gases, are particularly effective in trapping the sun's heat.

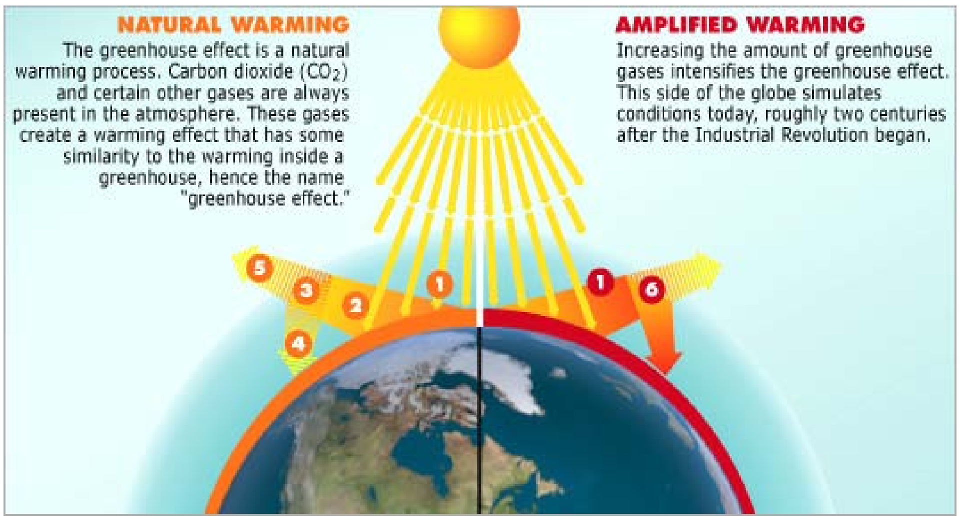
Weather or Climate?

Weather describes current or short-term atmospheric conditions, such as temperature, wind, sunshine, cloudiness, precipitation, etc.

Climate describes the generally prevailing weather conditions – globally or for a region –over an extended period of time, typically 30 years.

Climate scientists like to say: "Climate is what you expect; weather is what you get."

Figure 1 - Greenhouse Effect



1. Sunlight brings energy into the climate system; most of it is absorbed by the oceans and land.

THE GREENHOUSE EFFECT:

2. Heat (infrared energy) radiates outward from the warmed surface of the Earth.
3. Some of the infrared energy is absorbed by greenhouse gases in the atmosphere, which re-emit the energy in all directions.
4. Some of the infrared energy further warms the Earth.
5. Some of the infrared energy is emitted into space.

AMPLIFIED GREENHOUSE EFFECT:

6. Higher concentrations of CO_2 and other "greenhouse" gases trap more infrared energy in the atmosphere than occurs naturally. The additional heat further warms the atmosphere and Earth's surface.

Source: Marian Koshland Science Museum, National Academy of Sciences[1]

Water vapor is the most prevalent greenhouse gas. However, it has a brief residence time in the atmosphere and is not significantly associated with human activities. Consequently, most attention is given to more persistent greenhouse gases.

The Kyoto Protocol, an international treaty to fight global climate change, recognizes four greenhouse gases and two families of gases as the most important causes of climate change (Table 1). The degree to which greenhouse gases trap atmospheric heat is called the global warming potential (GWP), and is expressed as a multiple of the heat-trapping potential of carbon dioxide.

Table 1 shows the other major greenhouse gases: methane (natural gas), nitrous oxide (laughing gas), and sulfur hexafluoride. Two families of fluorinated gases, hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs), are also greenhouse gases.

Table 1 – Greenhouse Gas Warming Potentials (GWP)

Greenhouse Gas	GWP
Carbon dioxide (CO_2)	1
Methane (CH_4)	21
Nitrous oxide (N_2O)	310
Sulfur hexafluoride (SF_6)	23,900

Source: Intergovernmental Panel on Climate Change[2]

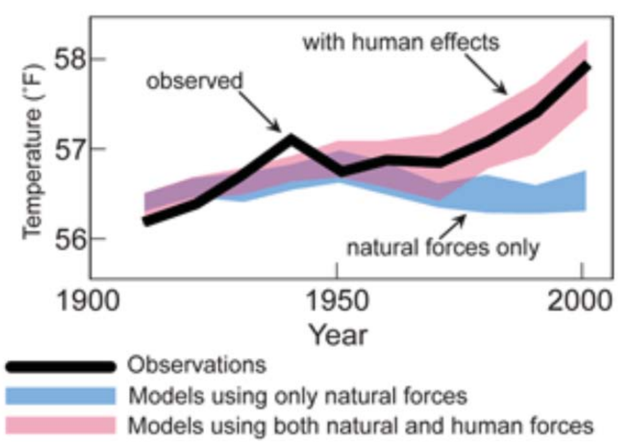
Climate scientists have observed that our climate has changed since 1900, with the most dramatic changes occurring since 1970. As stated by the United Nations' Intergovernmental Panel on Climate Change:

> *Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level*.[3]

Human activities, particularly fuel combustion, have increased the atmospheric concentration of carbon dioxide and other greenhouse gases. Although it is a source of political controversy, there is overwhelming agreement in the scientific community that these observed changes in climate are due to the increase of greenhouse gases (GHG) in the atmosphere as a result of human activities.

Climate scientists use complex computer models to project how the climate may change under different future scenarios. Model builders often account for variables that affect climate differently, so climate projections for similar scenarios using different models may give different results. Many studies look at climate projections using several models in order to better understand the possible range of future changes. Climate models have improved in recent years, and their abilities to describe the changes in climate that occurred in the 20th century provide more confidence in their projections of climate change in the 21st century. When the models are applied to historical data they support the position that observed temperature increases are caused by human activities, rather than just natural cycles (Figure 2).

Figure 2 – Global Climate Models Indicate Warming is Due to Human Activities



Source: National Oceanic and Atmospheric Administration[4]

Simulated global temperature in experiments that include human influences (pink line), and model experiments that included only natural factors (blue line). The black line is observed temperature change.

A variety of future scenarios can be used to answer "what if" questions about how changes in future population growth, energy sources and use, the economy or technology might affect the climate in the future. Researchers frequently present a range of projections, based on specific scenarios. Typically, studies look at a "lower" emissions scenario, with extensive energy conservation measures employed and an aggressive shift from fossil fuels to renewable energy. This scenario is typically contrasted with a "higher" emissions scenario, with continued and increasing reliance on fossil fuels (a "business as usual" scenario). Currently, we are on a higher emissions trajectory. Because most greenhouse gases last for a long time in the atmosphere, atmospheric greenhouse gas concentrations are expected to increase until mid-century before starting to decline. Consequently, even the "lower emissions" scenario predicts changes in climate – although less severe than predicted for the "higher emissions" scenario.

This ECOS analysis report reviews and summarizes the results of model-based research done by other credible entities. Because of the complexity of the climate models and the detailed understanding of climate science required to interpret climate model results, CCRPC has not conducted its own climate modeling. Our review of climate projection research focuses on studies that specifically address climate projections for the Northeastern United States, New England, Vermont or the Lake Champlain Basin.

CLIMATE CHANGE INDICATORS AND TRENDS

Climate researchers use a suite of indicators to identify whether climate change is occurring. Historical records of temperature, ice cover, growing season and precipitation are analyzed for statistically significant trends. In coastal areas, sea level records are also analyzed.

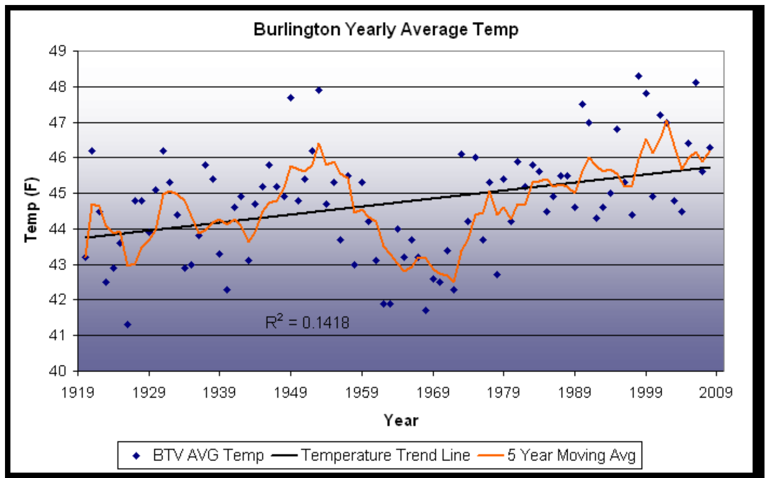
Several studies in recent years have specifically evaluated climate changes and projections for the Northeastern United States[5], Vermont[6] and the Lake Champlain Basin[7].

Average Temperature

The National Weather Service maintains long-term records of temperature readings taken at the Burlington International Airport.

Analyses of historical temperature data from the Burlington International Airport show an increase in the yearly average temperature of almost 2°F over the past 90 years (Figure 3). Much of this increase has occurred in the last 50 years.[8]

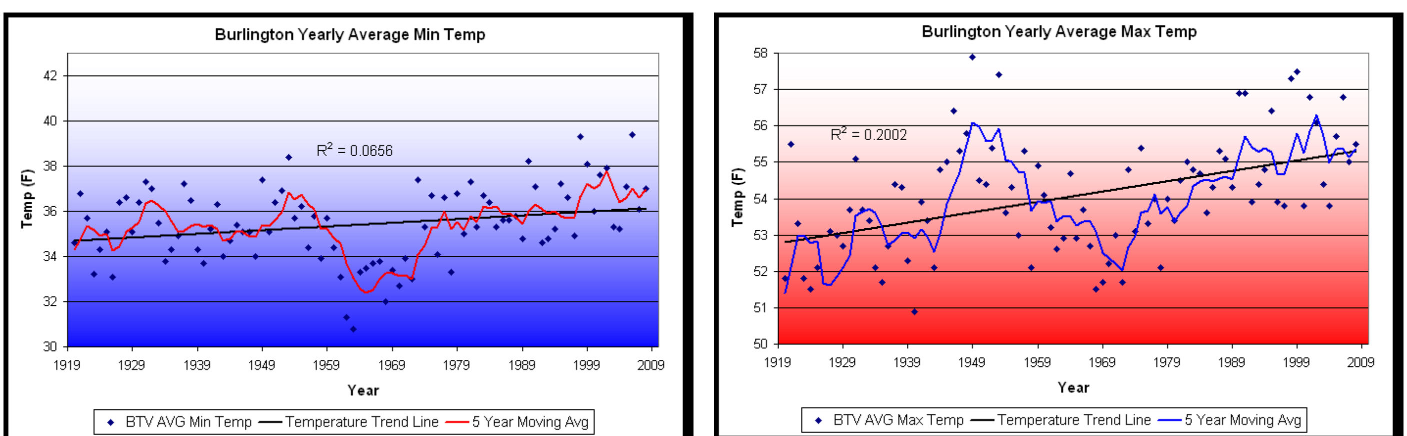
Figure 3 – Burlington Average Annual Temperature Has Increased



Source: National Weather Service[9]

Over the past century, winters have become warmer and summers have become hotter. The yearly average minimum temperature has increased about 1.5°F and the average maximum temperature has increased about 2.5°F (Figure 4). These observations are consistent with analyses for the entire Northeast.

Figure 4 – Burlington Average Minimum and Maximum Temperatures Have Increased



Source: National Weather Service[10]

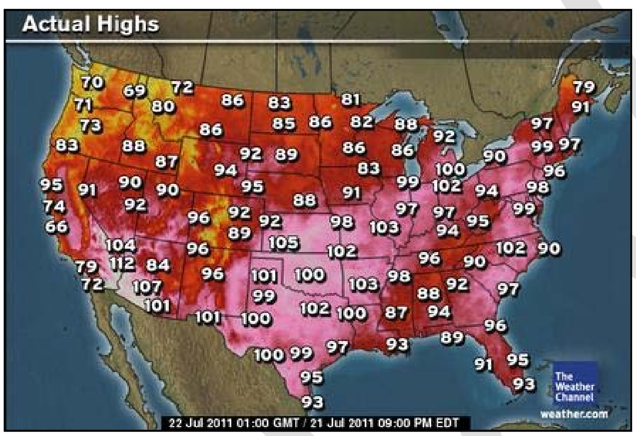
Climate modeling studies project that temperatures will continue to increase over the next several decades, with more warming in the winter than in the summer. The Northeast Climate Impacts Assessment used three different global climate models to evaluate a lower emissions scenario and a higher emissions scenario. Table 2 shows the temperature increases projected at mid-century and at the end of the century.

Table 2 – Northeast Temperatures Are Projected to Increase

	Mid-Century		End of Century	
	Low-Emissions	High-Emissions	Low-Emissions	High-Emissions
Summer	+ 2-5°F	+ 4-8°F	+ 3-7°F	+ 6-14°F
Winter	+ 4-5°F	+ 4-7°F	+ 5-8°F	+ 8-12°F

Source: Frumhoff, P.C., et al[11]

Under the lower emissions scenario, summer temperatures are expected to increase 2-5°F by mid-century and 3-7°F by the end of the century, with winter temperatures increasing 4-5°F by mid-century and 5-8°F by the end of the century. This compares to a higher emissions scenario projections of summer temperatures increasing 4-8°F by mid-century and 6-14°F by the end of the century, and winter temperatures increasing 4-7°F by mid-century and 8-12°F by the end of the century.



The average number of days each year in the Northeast that exceed 90°F has approximately doubled over the past 45 years.[12] Across the northern part of the Northeast region (such as Vermont), temperatures currently exceed 90°F approximately 5 days per year.

As shown in Table 3, climate models project extreme heat days in the Northeast to increase to around 30-60 days by the end of the century.

Table 3 – Northeast Extreme Heat Days Are Projected to Increase

	End of Century	
	Low-Emissions	High-Emissions
Days above 90°F	+ 30 days	+ 60 days
Days above 100°F	+ 3-9 days	+ 14-28 days

Source: Frumhoff, P.C., et al[13]

Three or more consecutive days over 90°F are considered to be heat waves. From 1990 to 2010, the National Weather Service in Burlington recorded an average of 0.85 heat waves/year.[14] Given the projected increase in summertime temperatures, the number of heat waves can be expected to increase under either emissions scenario.

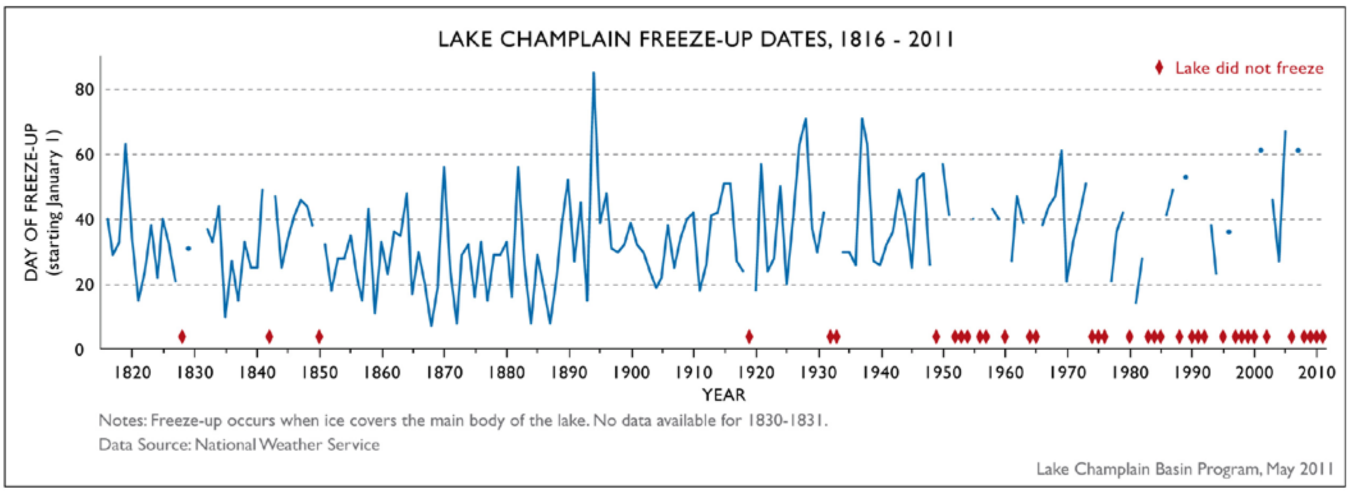
Lake Ice Cover

In northern regions, like Chittenden County, climate researchers often look at dates for when rivers and lakes become covered in ice (ice-in or freeze-up) and when the ice cover breaks up (ice-out). Ice-in and ice-out records are consistent with the warming trend in annual and winter temperature records.

The National Weather Service has historical records for the date when the main body of Lake Champlain iced over (Figure 5). The lake now freezes over approximately 8 days later than it did in the second half of the 1800s.

Even more striking are the years when the lake did not freeze at all. Since 1975, the lake has frozen over in only about half of the winters.

Figure 5 – Later Ice-In for Lake Champlain



Source: Lake Champlain Basin Program[15]

Although not specifically addressed by the climate modeling studies, warmer winter temperatures can be expected to continue the trend for later lake ice-in and earlier lake ice-out.

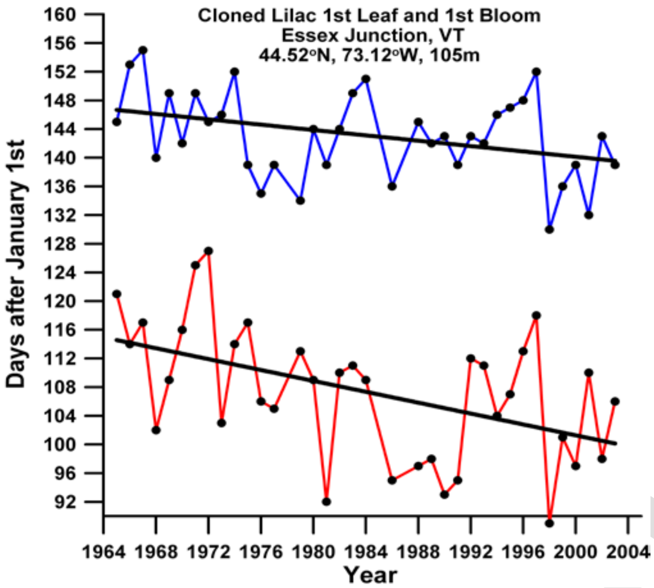
Growing Season

Lilacs have long been appreciated both for their beauty and for being heralds of spring. Consequently, there are extensive historical records in Vermont and around the country for when lilacs leaf out and when they bloom. Scientists have been looking at these records to identify whether spring is coming earlier.

First-leaf dates are an indicator of the start of the growing season for frost-tolerant plants. First-flower dates are an indicator of the start of the growing season for frost-sensitive plants.

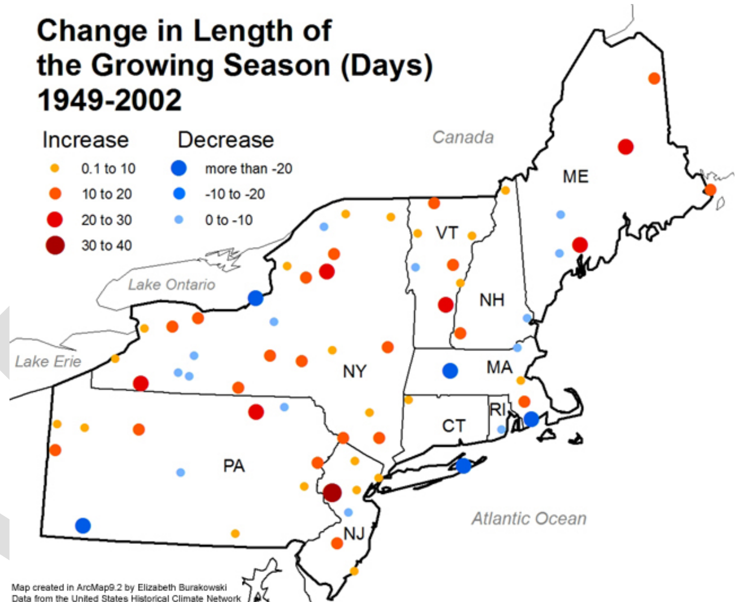
Analyses of 40 years of Vermont lilac records show that first leaf has been coming almost 3 days per decade earlier, while first bloom has advanced more slowly, by about 1.5 days per decade. A graph of lilac records from Essex Junction shows this pattern (Figure 6). Similar earlier blooming in the Northeast has been identified for apples and grapes.

Figure 6 – Lilacs Indicate Earlier Spring



Red line is first leaf. Blue line is first bloom.
Source: Schwartz, M.D.[16]

Figure 7 –Growing Season Has Increased



Source: New England Integrated Sciences & Assessment[17]

The growing season is determined both by the end of freezing temperatures in the spring and by the beginning of freezing temperatures in the autumn. Growing season trends have not been uniform across the Northeast; growing seasons in some areas have decreased but in many areas the growing season has gotten longer (Figure 7). Over the last 60 years, the growing season in Burlington has increased up to one week.

Climate modeling indicates that these trends are projected to continue and accelerate into the future. Table 4 shows the Northeast Climate Impact Assessment projections for first leaf and bloom, summer, and the growing season.

Table 4 – Northeast Growing Season Is Projected to Increase

	Mid-Century		End of Century	
	Low-Emissions	High-Emissions	Low-Emissions	High-Emissions
First Leaf & Bloom	--	--	1-2 weeks earlier	3 weeks earlier
Summer Starts	6 days earlier	11 days earlier	9 days earlier	21 days earlier
Summer Ends	10 days later	16 days later	12 days later	21 days later
Growing Season	2-4 weeks longer	2-4 weeks longer	4 weeks longer	6 weeks longer

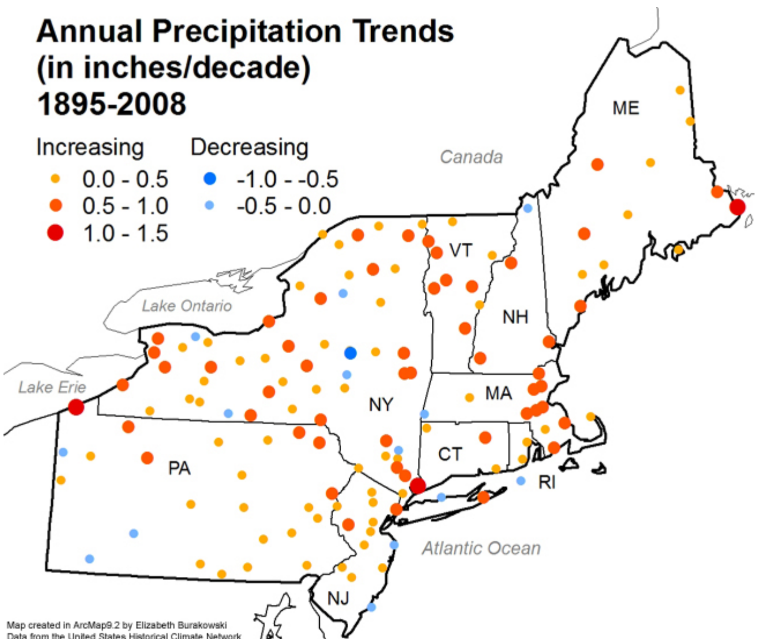
Source: Frumhoff, P.C., et al[18]

By the end of the century, plants are projected to leaf out and bloom 1-2 weeks earlier under the lower emissions scenario, and 3 weeks earlier under the higher emissions scenario. The growing season is projected to be 2-4 weeks longer by mid-century; by the end of the century the growing season is projected to be 4 weeks longer under the lower emissions scenario and 6 weeks longer under the higher emissions scenario.

Precipitation

Analysis of historic precipitation records reveals that annual precipitation has increased over the past century. Precipitation in Burlington has increased up to an inch for every decade since 1895 (Figure 8). The greatest increases in precipitation in the Northeast have occurred near major water bodies, including Lake Champlain.

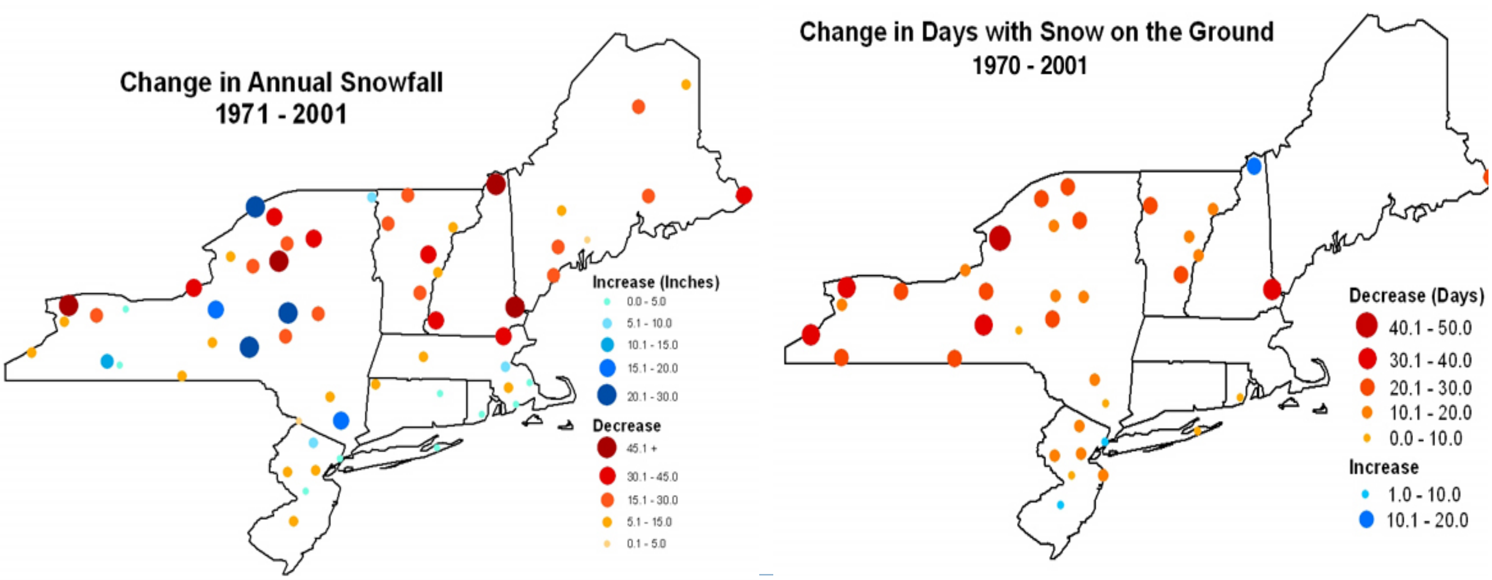
Figure 8 – Precipitation Has Increased



Source: New England Integrated Sciences & Assessment[19]

Warmer winter temperatures generally mean that more precipitation falls as rain, rather than snow. A recent analysis of snowfall in Burlington from 1906-2009 shows a substantial increase in seasonal snowfall.[20] However, the data also show greater variability after 1960. A different analysis of annual snowfall in Burlington shows a decrease of over two feet of annual snowfall between 1971 and 2001 (Figure 9).

Figure 9 – Snowfall and Snow Cover Have Decreased



Source: New England Integrated Sciences & Assessment[21]

Because of the warmer temperatures, the snow that does fall is wetter – or more "slushy" – and doesn't stay on the ground as long. From 1970-2000, there were approximately 25 fewer days with snow on the ground.[22]

Table 5 – Northeast Precipitation is Projected to Increase

	End of Century	
	Low-Emissions	High-Emissions
Annual Precipitation	+10%	+10%
Winter Precipitation	+20-25%	+25-30%

Source: Northeast Climate Impacts Assessment[23]

Precipitation is projected to increase over the century, with most of the increase occurring in winter (Table 5). A higher proportion of winter precipitation is expected to fall as rain, instead of snow.

Individual extreme weather events, such as the 2011 Lake Champlain spring flooding or Tropical Storm Irene, are difficult to link to climate change. However, climate change is expected to result in more weather events of this type. Table 6 shows the projected increase in extreme precipitation events in the Northeast under either the lower or higher emissions scenario.

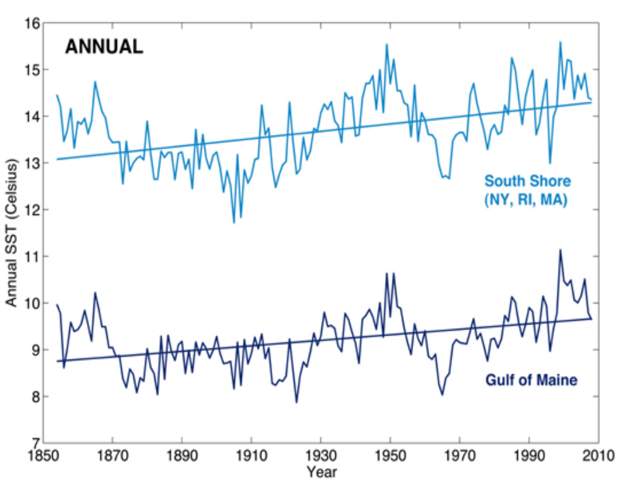
Table 6 – Northeast Extreme Event Precipitation is Projected to Increase

	Mid-Century	End of Century
Precipitation Intensity	+ 8-9%	+ 10-15%
Number of Heavy Precipitation Events	+ 8%	+ 12-13%
Amount of Rain During Extreme Events	+ 10%	+ 20%

Source: Northeast Climate Impacts Assessment[24]

Under either emissions scenario, precipitation intensity (the average amount of rain that falls on a rainy day) is projected to increase 8-9% by mid-century and by 10-15% by the end of the century. The number of heavy precipitation events is projected to increase, and the amount of rain falling during an extreme event is projected to increase 10% by mid-century and 20% by the end of the century. This change in precipitation and intensity has implications for future flood events (see impacts discussion below).

Figure 10 – Sea Surface Temperature Trends



Source: New England Integrated Sciences &Assessment [25]

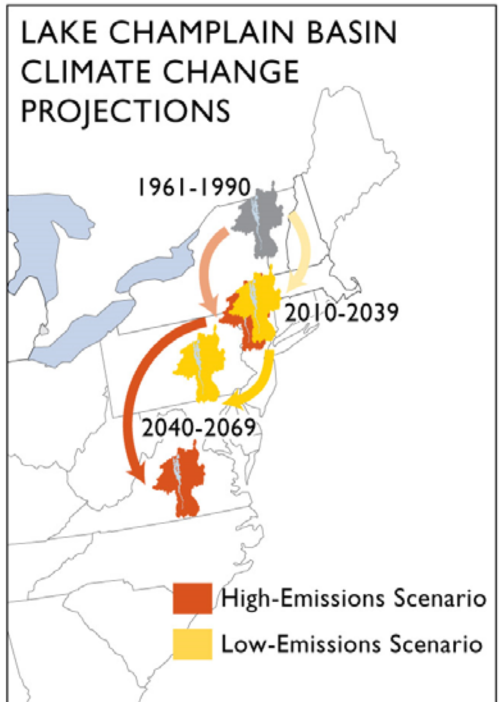
One of the reasons for this increase in extreme precipitation events rests with ocean surface temperature for the Gulf of Maine and the South Shore, between Cape Cod and Long Island. The average ocean surface temperature has increased (Figure 10), allowing tropical storms and nor'easters to pick up more moisture. As with Tropical Storm Irene, when these storms hit Vermont, they hold more moisture which generates more intense precipitation.[26]

Despite the projected increase in precipitation, there is also the potential for increased drought. Drought occurs when monthly soil moisture falls more than 10% below the long-term mean. Combined trends in less snowpack, earlier snow-melt, steady summer-time precipitation and higher summer temperatures can result in decreased summer-time soil moisture. Historically, northern New England has had short-term droughts (lasting 1-3 months) about once every two to three years. Under the higher emissions scenario, short-term droughts may be as frequent as once per year.[27]

IMPACTS OF PROJECTED CLIMATE CHANGES

Most climate projections predict that our climate will become warmer and wetter. Instead of the climate that we currently associate with northern New England, our future climate will be more like the recent climate in the Mid-Atlantic. Figure 11 shows how the summertime climate for the Lake Champlain Basin (including Chittenden County) is projected to change.[28] By mid-century, under either a lower or higher emissions scenario, summers will feel like southeastern New York. Under the lower emissions scenario, end-of-century summers are projected to feel like Pennsylvania; under the higher emissions scenario, end-of-century summers are projected to feel like Virginia.

Figure 11 – Summer Climate Projected to be Like Today's Mid-Atlantic



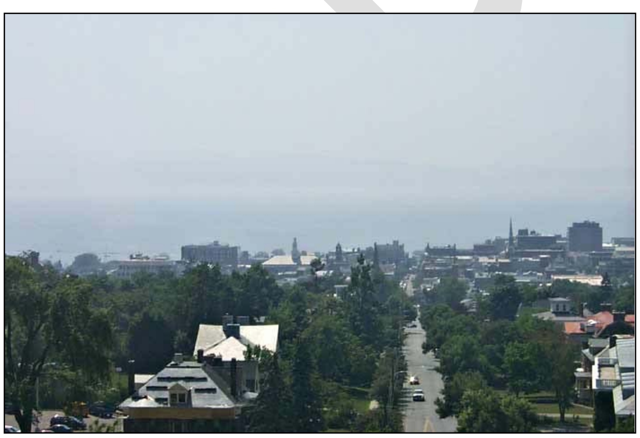
Red arrows track the shift in the Lake Champlain Basin's summer climate over the next 60 years if we continue under a high-emissions scenario. Yellow arrows track the shift under a low-emissions scenario.
Data Source: Union of Concerned Scientists
Lake Champlain Basin Program, January 2011

These changes will impact our environment, public health, our built environment and our local economy. Although the magnitude of the impacts is often difficult to quantify, the direction and implications of the impacts are discussed in the following sections.

Environmental and Natural Resource Impacts

Air Quality

Air quality monitoring confirms that Chittenden County's air quality currently meets all national standards. However, the concentrations of ground-level ozone – a major component of smog – are close to the current standard. The national ozone standard is scheduled for re-evaluation in the next few years; current health research supports making the ozone standard stricter. Ozone levels in Chittenden County would likely not comply with recent proposals for the standard.[29]



Ground-level ozone is formed through chemical reactions of hydrocarbons and nitrogen oxides in the atmosphere. Warmer temperatures promote these reactions. The higher temperatures projected for our region, particularly in the summer, will increase the levels of ground-level ozone. In addition to the health impacts of ozone, exceeding the national air quality standard for ozone would trigger a complex regulatory framework that places additional pollution control restrictions on industries and adds expensive steps to planning for transportation projects. These regulations would add costs to businesses with air emissions, and to state and local governments involved with transportation and development planning.

Water Resources

The projected changes in climate for our regions will significantly impact our water resources. High flow events are projected to occur more frequently, possibly by as much as 80%.[30]

With warmer weather and more winter precipitation falling as rain, more high-streamflow events will occur in winter and spring peak flows are projected to occur 7-9 days earlier by mid-century and 10-14 days earlier by end-of-century.[31]

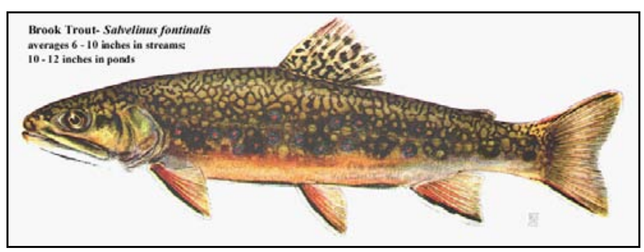
Increased precipitation and precipitation intensity will intensify storm water runoff, particularly in areas with impervious surfaces. This will increase the potential for flooding.

Reduced snowpack and earlier snowmelt may reduce the replenishment of groundwater and reduce summer and fall streamflows. With little change in summer precipitation, summer low-flow periods would be longer and more pronounced. Under the higher emissions scenario, low streamflow periods would be extended by almost a month by late century.[32]

Increased stormwater and flooding may also increase water pollution as a result of increased flow carrying pollutants, such as eroded sediments, fertilizers, road sands, animal wastes, inundated septic systems, and other nutrient-rich pollutants into rivers and lakes.[33] Higher water temperatures can allow for greater incidence of mercury methylation, resulting in increased accumulation of mercury in the aquatic food chain.[34] Coupled with nutrient loading, warmer waters encourage more frequent blooms of toxic blue-green algae and *E. coli* bacteria.[35]

Natural Communities

Aquatic ecosystems are particularly at risk from the effects of projected climate change.



- Warmer waters hold less dissolved oxygen. Many cold-water aquatic species, such as trout, are sensitive to oxygen requirements.[36]
- Increased periods of low summer flow may decrease aquatic habitats, making them more isolated and oxygen poor. Changes in the timing and duration of low and high flows could interfere with the life cycles of aquatic insects or migratory fish.[37]
- Similarly, riparian areas with little or no vegetative buffer will experience higher thermal stress. Tree species important for riparian buffers may themselves be sensitive to increased temperatures.[38]
- Species interactions may be disrupted, as more tolerant species gain competitive advantages and communities become less resistant to invasive species. Aquatic species that are particularly vulnerable include those sensitive to warmer temperatures and oxygen poor waters

(brook trout), those sensitive to sedimentation (fresh water mussels), and those susceptible to mercury contamination (loons).[39]

- Forest communities will also be impacted by the projected changes to our climate. Climate modeling predicts that the habitat suitable for most of the region's tree species is projected to move northeast as the climate continues to warm. Under the lower emissions scenario, this shift is projected to be about 350 miles during this century, and about 500 miles under the higher emissions scenario.[40]
- By the end of the century, the dominant maple/beech/birch forests of the Champlain Valley are expected to remain unchanged in the lower emissions scenario, but would gradually shift to a dominant oak/hickory forest under the higher emissions scenario.[41] This doesn't mean that all of the maple, beech and birch trees would disappear. Trees can persist in areas where the climate isn't well suited to them, however they may become less productive and more vulnerable to competition and other stresses.
- Spruce/fir forests are particularly vulnerable to climate change. In addition to decreased climate suitability for the trees, these forests are home to several species that are already at the southern edge of their range, such as snowshoe hares, American marten, and the endangered Canada lynx. These species are vulnerable to further loss of habitat.[42]
- Certain tree species face multiple threats from climate change. Suitable habitat for hemlock trees is projected to dramatically decline by the end of the century. Additionally, warming temperatures will aid in the northward spread of the hemlock wooly adelgid. The hemlock wooly adelgid is a non-native insect pest that has destroyed hemlock stands from the Southeast to southern New England. Hardwood trees that typically replace hemlocks, such as birch, are less effective in shading and cooling streams. This adversely affects aquatic species such as brook trout and the insects they feed on. Hemlock loss has also been shown to change soil characteristics, speed up nutrient cycling and increase nitrate runoff into streams.[43]

Forests provide a variety of ecosystem services, such as timber, recreation, wildlife habitat, nutrient cycling, soil conservation, pollutant filtration, and carbon storage. Projected climate warming will affect these services both positively and adversely. Increasing atmospheric concentrations of carbon dioxide and a longer growing season are likely to increase overall forest productivity. This could result in a net increase in carbon storage. However, these benefits may be offset by increasing storms, wildfires, insect infestations, forest clearing or other human land uses.[44]

Public Health Impacts

The number of high heat days is projected to increase. High heat days increase the risk of heat stress and even death, particularly for the elderly and very young.[45] Programs to educate and warn vulnerable populations, as well as providing cooling shelters, can help reduce extreme heat health impacts. Conversely, warmer winter temperatures will reduce mortality from the cold.

Increasing precipitation could result in increased deaths, injuries and illnesses related to flooding.[46]

Warmer and wetter weather will make it easier for insects and diseases to migrate to and survive our region. Mosquitos carry the West Nile virus. Warmer winters, hotter summers and heavy rainstorms alternating with summer dry periods are conducive to increased outbreaks of West Nile virus disease. Similarly, a warmer climate will make it easier for tick-borne Lyme disease to spread into our region.[47]

Seasonal pollen production increases under warmer temperatures and higher atmospheric carbon dioxide concentrations. These conditions could extend the allergy season, exacerbate seasonal allergy symptoms, and increase pollen-triggered asthma risks.[48]

Increased ground-level ozone concentrations also increase the risks of respiratory illnesses. Children, the elderly, people already suffering from respiratory diseases, and outdoor athletes are most at risk from ozone exposure. Common symptoms of ozone exposure include: shortness of breath; dry cough or pain when taking a deep breath; aggravation of asthma, emphysema and other respiratory diseases; and increased risk of respiratory infections, such as pneumonia and bronchitis.[49]

Built Environment Impacts

Flooding and Stormwater

Increasing winter and spring precipitation, particularly as rain, poses an increased risk of flooding of lakes, rivers and streams. Earlier ice break up on rivers and streams coupled with earlier high flow events may increase flooding due to ice jams. Increased winter and spring precipitation, particularly when soils are frozen or saturated, will increase runoff and the likelihood of high flow events.[50]

Infrastructure located in flood-prone shorelines and along streams with high levels of encroachment are particularly at risk.[51] The 2011 Spring flooding of Lake Champlain demonstrated how roads, homes and other shoreline structures can be susceptible to lake shore flooding. Similarly, Tropical Storm Irene in August 2011 showed how Vermont's historic settlement patterns along rivers and streams puts entire communities at risk of flooding. Homes, businesses, embankments and transportation infrastructure can all be damaged by inundation or erosion from flooding. Dams are also susceptible to accelerated sediment buildup behind structures and may be subject to elevated risk of failure during high flow events; increased flow from water-level management or dam failure poses additional flood risks to downstream structures in the flood hazard area.[52]

Transportation Systems

The roads, bridges, culverts and railways that comprise our transportation system connect our lives with our communities, and our communities with the rest of Vermont. The projected increase in extreme weather and flooding poses particular risks to our transportation systems.

Inundation, fallen trees and downed power lines can all cause disruption to roads, bridges and rail lines. When the transportation system is closed, even temporarily, the movement of people and goods is disrupted, with accompanying impacts to the economy and people's lives.[53]

As we learned from Tropical Storm Irene, flooding and erosion can also cause tremendous damage to transportation infrastructure. Culverts, roads and railways can be damaged from erosion. Increased streamflow can scour and undermine bridges. Higher wind loadings during storms can also affect bridges. Increasing freeze-thaw cycles may adversely affect the service life of roadbeds and pavement.[54]

Water Supply and Wastewater Treatment Systems

Both municipal and private water supply and wastewater treatment systems may be impacted by projected changes to our climate.

During floods, water wells and treatment infrastructure may be physically damaged by erosion or contaminated by inundation. Erosion and turbidity during extreme weather are likely to increase water quality problems. Heavy rainfall, surface runoff and flooding have also been linked to outbreaks of waterborne diseases caused by pathogens such as Giardia and Cryptosporidium.[55]

Increased runoff during precipitation events may cause overflows in areas with combined sewers, like some parts of Burlington. Combined sewer overflows can result in water quality problems.[56]

The increased potential for summertime droughts is also a concern for public and private water supply systems. Heat waves increase demand for water; there may be shortages during droughts when aquifers are not being replenished and streams have low flow.[57] This is particularly a concern for rural areas that rely on groundwater and for communities, such as Bolton Valley Resort, that rely on streams for water supply.

Energy Demand and Supply Systems

The changes projected for our climate have implications for energy demand. With warmer winters, the energy demand for heating is expected to be reduced. In Chittenden County, the primary thermal energy sources are fuel oil, natural gas, propane and wood.[58] However, hotter summers – and heat waves especially – will result in a greater energy demand for cooling, predominantly powered by electricity.

Projected climate changes will also affect electricity production and distribution systems.[59] Thermoelectric power production is less efficient during heat waves. Hydroelectric power potential is reduced during droughts and sometimes during flooding events. Tree falls from increased storm winds and ice storms will increase the potential for power outages. Increased electricity demand during heat waves may result in localized or grid-scale stresses on the distribution system, causing brownouts or blackouts.

Local Economy Impacts

Agriculture and Food Supply

The changes in climate projected for our region are likely to have mixed impacts on local agriculture and our local food supply: some aspects of climate change will be harmful and others may be beneficial for farmers able to adapt to the changes.

Dairy still accounts for 50% of all agricultural sales in Chittenden County.[60] Depending on humidity, milk production is optimal between 40-75°F. Higher temperatures can cause heat stress and depress milk production and birthing rates.[61] These impacts can be mitigated by changes ranging from management and operational changes (lower cost), ventilation and insulation of barns (moderate cost), or installation of new buildings with air conditioning (higher cost).[62] Dairy farming is already a challenging enterprise; many farmers may not be able to adopt these changes without financial assistance. Farmers that are able to adapt may benefit from the loss of dairy production further south.

Many of the high-value horticultural crops produced in Chittenden County, such as apples, grapes and berries, require long winter chill periods. As winter temperatures warm and the growing season lengthens, yields of these crops can be expected to decline. Farmers may be able to adapt by shifting to crop varieties better suited to warmer conditions, however such transitions can be costly and take time.

Warmer climate conditions do not favor maple sugar trees, and would reduce the length of the sugar season and the quality of the syrup.

Warmer winters will favor the spread of diseases, weeds and insect pests, putting additional economic pressures on farmers – particularly organic producers. Under the lower emissions scenario, crop impacts are expected to be relatively minor. Under the higher emissions scenario, the northward expansion of agricultural pests and weeds are projected to negatively affect crop production by late century.[63]

Summer heat stress particularly affects some cool-weather crops, such as cabbages, potatoes and apples.[64]

Increasing variability in precipitation will also adversely affect crop yields. Increased flooding can erode fields, destroy crops or delay planting. Crops in waterlogged fields are more susceptible to root diseases. Longer and more frequent summer droughts decrease the soil moisture available to plants and can also depress yields. Irrigation may become necessary for some crops.

Increasing concentrations of carbon dioxide in the atmosphere can act as a fertilizer. Growth of some crops may be enhanced, but this may be offset by other aspects of climate change, such as temperature, precipitation and rising ozone levels. Weeds can also benefit from this fertilizer effect. The positive effects of carbon dioxide on plant growth are unlikely to outweigh the negative effects of heat stress.[65]

Yields for some commodity crops, such as corn, soybeans and wheat, may increase under moderate climate change conditions. Warmer conditions and a longer growing season will favor crops such as tomatoes, peppers, watermelons, peaches and European red wine grapes.

Climate researchers note that some of the impacts of climate change are already occurring in the Northeast.[66] They attribute the success of the European wine grape industry in upstate New York, in part, due to less severe winters and reduced risk of vine and root rot. However, they also note that apple yields in Western New York have fallen in years with warmer winters, possibly due to poorer fruit set.

Although problematic, the impacts of climate change in our region may be less severe than in other regions and other countries where agriculture is more vulnerable.[67] Farms able to adopt management practices, crop selection and technology will be better able to adapt to new climate conditions. Market opportunities may arise if agriculture in other regions is more severely affected. However, food supply may also be affected by decreased supply from more vulnerable regions.[68]

Forestry

The climate changes projected to occur in our region are expected to result in changes to our forests. The dominant maple, beech and birch trees that are characteristic of our forests are not as well-adapted to warmer and wetter conditions as other species, such as oak and hickory. Spruce/fir forests are particularly vulnerable, as are animal species dependent on them: Canada lynx, snowshoe hare and Bicknell's thrush.

Many factors contribute to how well any given species can persist or migrate to new locations. Soil suitability, rates of seed dispersal, competition from other species, stress from warmer temperatures or drought, and encroachment of development can all affect how well species and natural communities will persist or migrate. However, a gradual transition to a different combination of forest species is likely to occur over the course of this century.[69]

Warmer and wetter conditions are also expected to increase the spread of invasive species, such as buckthorn and Japanese honeysuckle. Similarly, insect pests and diseases may also spread. Besides the hemlock woolly adelgid, foresters have been monitoring the northward spread of the emerald green ash borer. Other pests that may benefit and speed forest species transition include: the spruce budworm, pine bark beetle, gypsy moth, balsam woolly adelgid, Dutch elm disease, white pine blister rust, and beech bark disease.[70]

Increasing concentrations of atmospheric carbon dioxide may cause increased photosynthesis in some plants, which with warmer temperatures and a longer growing season may result in increased growth rates. This may affect the efficiency of water use and increase plant demands for soil nutrients. Some invasive species, such as kudzu and Canada thistle, have been shown to have a strong growth response to increased carbon dioxide levels, and their spread may also accelerate.

Climate changes projected under the lower emissions scenario are not predicted to significantly alter our forests in this century, but major changes are predicted under the higher emissions scenario.[71]

The economic impacts on the forestry sector are unclear. Climate change would alter the types of trees harvested. Increased forest productivity might be offset by costs for harvesting under conditions of increased precipitation and soil erosion.

Recreation and Tourism

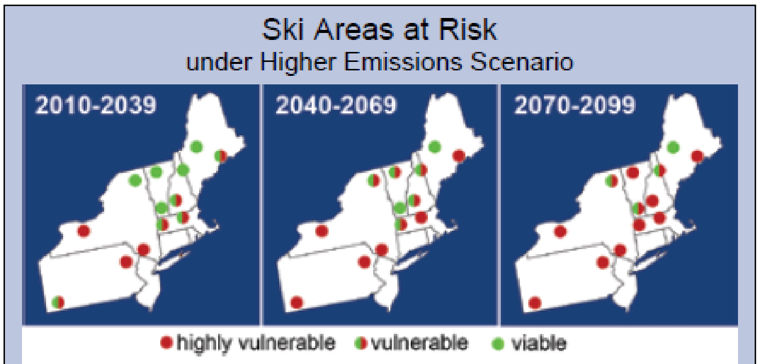
The changes projected for our climate will significantly affect recreation and tourism in our region.

Longer summers may increase opportunities for swimmers, boaters, hikers and bicyclists. However, heat waves will pose problems for outdoor recreation and blue green algae blooms can make shallow waters unsafe to swim in. Access to some beaches and shoreline recreation areas may be limited if lake levels rise. Recreational fishing may have to change as populations of cold water fish are displaced by warm water species. Severe and unpredictable weather can increase the danger for outdoor recreationists.[72]

The increased growing season will likely make the fall foliage season shorter and later in the year. Displacement of our dominant maple, beech and birch trees – particularly the iconic sugar maple – will result in the autumn leaves being less colorful.

Winter recreation and tourism will be most impacted by climate change. Ice fishing and pond hockey require solid lake ice conditions, which will become increasingly unpredictable. Snowmobiling, snowshoeing and cross-country skiing depend on sufficient natural snowpack. Warmer winters and increased rainfall will reduce snowfall reliability and depth. Under the lower emissions scenario, the snowmobile season may be reduced to about 40 days; under the higher emissions scenario, the season could be 27 days.[73] Snowmobile seasons of two months or longer will likely be restricted to northernmost and high elevation areas.[74]

Figure 12 – Climate Impacts to Alpine Skiing



The ski resorts in the Northeast have three climate-related criteria that need to be met for them to remain viable: the average length of the ski season must be at least 100 days; there must be a good probability of being open during the lucrative winter holiday week between Christmas and the New Year; and there must be enough nights that are sufficiently cold to enable snowmaking operations. By these standards, only one area in the region (not surprisingly, the one located farthest north) is projected to be able to support viable ski resorts by the end of this century under a higher emissions scenario.

Source: US Global Change Research Program [75]

As shown in Figure 12, alpine skiing is also vulnerable to climate change. Under the lower emissions scenario, ski areas are expected to persist, and may benefit from reduced competition. However, under the higher emissions scenario, ski areas may no longer be viable.[76] Ski areas may be able to maintain their season by artificially making snow. Cold temperatures are still required, however, and snowmaking is expensive. Ski areas depend heavily on holiday skiers for their financial viability. Ski revenues suffer from warm weather or rain during the holiday season.[77] In the long term, the ski industry viability the willingness of skiers to think about skiing when there is no snow in their own back yards.

CONCLUSIONS AND NEXT STEPS

Our climate is already changing. Key indicators of climate change all demonstrate that our region is getting warmer and wetter:

- The average annual temperature increased in the latter half of the 20th century; winter temperatures are warmer and summer temperatures are hotter. Temperatures are projected to continue to increase throughout the 21st century, and the number of extreme heat days is expected to increase.
- Lake ice cover has already decreased. Lake Champlain freezes over later than it used to, and increasingly doesn't freeze up at all. With the warmer winters projected by climate models, this trend is likely to continue.
- The growing season already starts earlier and lasts longer than it did 50 years ago. Climate models project that lengthening of the growing season will accelerate this century.
- Annual precipitation has already increased, but more falls as rain instead of snow. This trend is expected to continue in this century, with most of the additional precipitation occurring in the winter months.
- Extreme precipitation events are projected to be more frequent and more intense. Nevertheless, short-term drought conditions in summer are projected to be more frequent.

Climate modeling using a lower emissions scenario (aggressive emissions reduction) and a higher emissions scenario (continuation of current emissions trends) indicates that the changes in our climate will be less severe under the lower emissions scenario. Achieving the lower emissions scenario requires global reductions in emissions. Reducing county-level greenhouse gas emissions through mitigation strategies will reduce our contribution to the global problem. Many of the strategies identified in *Keeping Our Air Clean: Local and Regional Strategies to Improve Air Quality*[78] directly or indirectly reduce fossil fuel consumption; these strategies will also help mitigate climate change.

If our climate will change this century, even with mitigation, then it is appropriate to prepare for the reasonably foreseeable impacts of this change. Adaptation strategies that reduce potential losses or take advantage of potential opportunities can help the region be more resilient in the face of climate change impacts. Like insurance, adaptation is a risk management strategy: it has costs and it isn't fool-proof. However, not undertaking adaptation strategies also has costs and consequences.

Many communities, states, and a few regions have prepared, or are in the process of preparing, climate action plans that incorporate mitigation and/or adaption strategies. As the next step, Chittenden County Regional Planning Commission will work with our communities and stakeholders to undertake a climate action planning process for our region.

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