



UVLSRPC Regional Plan 2015

Chapter 9

Hazards and Adaptation

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9.1 HAZARD MITIGATION AND EMERGENCY PREPAREDNESS

Vision

The region's communities will proactively identify and implement hazard mitigation measures to protect health, safety, and property by eliminating or reducing damages from natural and human-made hazards.

Emergency Management

Governments, whether local, state, or federal, have the responsibility to provide emergency management to protect their citizenry. There are four approaches for a comprehensive emergency management program:

1. Hazard Mitigation –Actions taken to reduce or eliminate the probability of exposure to a hazard.
2. Preparedness –Having a plan so everyone knows what they must do during events, and having plans and facilities to assist in an emergency.
3. Response – When an emergency or disaster happens, response actions include notifying emergency management personnel of the crisis; warning, evacuating, and sheltering people; keeping the public informed; assessing damage; and requesting help from outside agencies.
4. Recovery – Recovery is restoring infrastructure and the social and economic life of the community.

Regional Emergency Response Cooperation

Municipalities have established several regional cooperative agreements and facilities to ensure that there are adequate shared resources available for responding to emergencies while reducing costs to each municipality. There are many different types of formal agreements in place in the region including:

- All municipalities are members of a Fire Mutual Aid organization.
- Approximately two thirds of municipalities belong to the Public Works Highway Mutual Aid Program.
- Emergency dispatch is a cooperative service in many towns to provide emergency communication coverage to every community for fire, police, EMS, ambulance, and highway.
- Some municipalities have contractual agreements with neighboring towns or other entities to provide emergency response and ambulance services as needed.

Tables in Appendix II summarize the mutual aid cooperation and current dispatch service areas for communities in the region.

Hazard Assistance Programs

The Federal Emergency Management Agency (FEMA) provides funding to New Hampshire municipalities through the Homeland Security and Emergency Management (HSEM) office for the purpose of assisting municipalities to develop hazard mitigation plans. For a municipality to be eligible for certain federal grants to mitigate known hazards, there are three requirements:

1. An up-to-date Hazard Mitigation Plan (every five years);
2. An up-to-date Local Emergency Operations Plan (every five years);
3. Participation in the National Flood Insurance Program.

Hazard Mitigation Planning

Flooding and severe winter weather top the list for hazardous events in our region's municipal hazard mitigation plans. If flooding were to occur in all flood plains in the region,

according to municipal plans, the estimated building damage would be close to \$180 million affecting close to 2,000 buildings.

The purpose of hazard mitigation planning is to reduce, avoid or eliminate the risk of loss of life or property likely to be caused by future natural disasters or emergencies; for example, some common hazard mitigation strategies are:

- Replacing a culvert with a larger one on a section of road that consistently floods every spring. This mitigates the risk of future road wash-outs and saves the municipality the expense of fixing road wash-outs every spring and the resulting interruption to travel.
- Installing lightning protection devices in buildings that have a history of being hit by lightning. This reduces the risk of fire and electrical surges damaging electronics including communications equipment and computers.
- Adopting regulations or ordinances to restrict further development in known hazard areas, such as the floodplain or on steep slopes.

Appendix II includes a summary table of the municipal hazard mitigation plan status for each community in the region.

Local Emergency Operations Planning

A Local Emergency Operations Plan (LEOP) is a guide for coordinating emergency response when an emergency or natural disaster occurs. It is often confused with the Hazard Mitigation Plan, but a hazard mitigation plan is intended to reduce or eliminate impacts from hazards before they occur, or before they can happen again. The LEOP process helps the municipality to prepare for responding to an emergency by defining and identifying: 1) Warning contacts and protocols; 2) Issuance and Dissemination of Emergency Public Information; 3)

Evacuation procedures and venues; and 4) Shelter-in-place and public shelter protocols.

Emergency Operations Plans align with the National Incident Management System (NIMS). This system was established after the 2001 terrorist attacks to provide a consistent, nationwide template for Federal, State, tribal and local governments to work with nongovernmental organizations and the private sector to prevent, protect against, respond to, recover from, and mitigate the effects of incidents. NIMS is not a plan itself, but a system to develop a plan that includes the following:

- Assign responsibility to organizations and individuals for carrying out specific actions at projected times and places in an emergency that exceeds the capability or routine responsibility of any one agency, e.g., the fire department.
- Set forth protocols outlining individual and organizational authority, relationships, responsibilities, and coordination of actions.
- Describe how people and property will be protected in emergencies and disasters.
- Identify personnel, equipment, facilities, supplies, and other resources available within the municipality or by agreement with other governmental entities, nonprofit organizations or even private businesses- for use during response and recovery operations.
- Identify steps to address mitigation concerns during response and recovery activities.

One important piece of the Local Emergency Operations Plan is the list of local, regional, and state emergency contacts. Local contacts may include local contractors with a backhoe or other heavy equipment or a local grocery store that could supply emergency food for a shelter. Regional contacts might include the New

Hampshire or Vermont Red Cross (which serves some NH Upper Valley towns), local Medical Emergency Response Corps, and other non-profit organizations.

National Flood Insurance Program

Participating in the National Flood Insurance Program (NFIP) is considered a hazard mitigation strategy because it allows property owners in the floodplain to obtain affordable flood insurance. Recent changes to the NFIP will affect some property owners that in the past received a federal subsidy on their flood insurance premiums; the federal subsidy is in the process of being phased out and premiums will rise substantially.

Eighty-five percent (85%) of the region's municipalities are participants in NFIP. There are only five buildings in the region that are considered "repetitive loss buildings" with a total payout for damages of \$210,000 since the beginning of the program. Repetitive loss simply means that the owners have submitted for damage payment more than once. There were 90 other flood insurance claims in the region at a value of \$1.7 million since the beginning of the program.

The New Hampshire Office of Energy and Planning administers the NFIP, which is a partnership between a community and the federal government to mitigate the risk for loss of lives and property. Communities participate by agreeing to adopt and enforce a floodplain management ordinance designed to reduce future flood risks and in return all residents in those participating communities can purchase flood insurance.

There is no fee to join NFIP. The NFIP regulations do not restrict development in the floodplain, but rather provide minimum regulations for building standards to reduce flood damage. A community has the option to adopt regulations that have more protective building standards than those

required by NFIP. If a community is not a participant in NFIP:

- Property owners will not be able to purchase NFIP flood insurance policies.
- Federal grants or loans for development will not be available in identified flood hazard areas under some federal programs.
- Federal disaster assistance for flood damage will not be provided to repair insurable buildings located in the identifiable flood hazard areas.
- Federal mortgage insurance or loan guarantees will not be provided in identified flood hazard areas.
- Federal insured or regulated institutions are allowed to make conventional loans for insurable buildings in flood hazard areas of non-participating communities—however, the lender must notify applicants that the property is in a flood hazard area and that the property is not eligible for Federal disaster assistance (some lenders voluntarily choose not to make these loans).

Disaster Declaration

In 1988, the Robert T. Stafford Disaster Relief and Emergency Assistance Act, 42 U.S.C. § 5121-5206, was enacted to support state and local governments and their citizens when disasters overwhelm them. This law, as amended, establishes a process for requesting and obtaining a Presidential Disaster Declaration, defines the type and scope of assistance available from the Federal Government, and sets the conditions for obtaining that assistance. FEMA, now part of the Emergency Preparedness and Response Directorate of the Department of Homeland Security, is tasked with coordinating the response.

The Stafford Act (§401) requires that: "All requests for a declaration by the President

that a major disaster exists shall be made by the Governor of the affected State.” State and Federal officials conduct a preliminary damage assessment (PDA) to estimate the extent of the disaster and its impact on individuals and public facilities. This information is included in the Governor’s request to show that the disaster is of such severity and magnitude that effective response is beyond the capabilities of the State and the local governments and that Federal assistance is necessary.

Based on the Governor’s request, the President may declare that a major disaster or emergency exists, thus activating an array of Federal programs to assist in the response and recovery effort.

Not all programs, however, are activated for every disaster. The determination of which programs are activated is based on the needs found during the damage assessment and

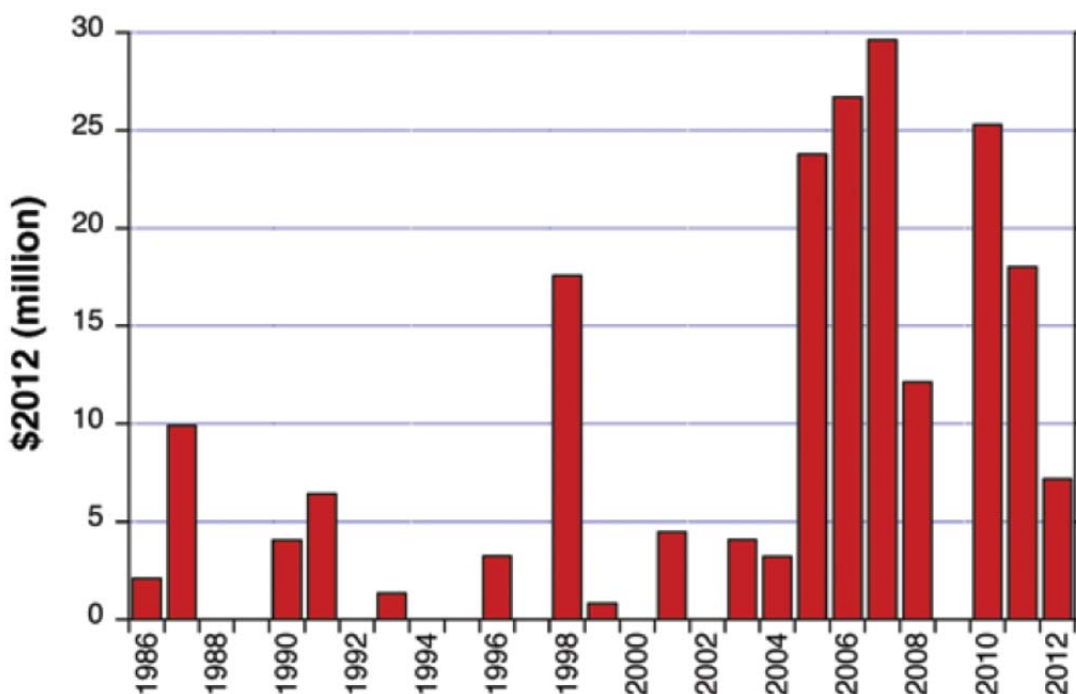
any subsequent information that may be discovered.

FEMA/Emergency Preparedness & Response disaster assistance falls into three general categories:

- Individual Assistance: Aid to individuals and households.
- Public Assistance: Aid to public and certain non-profit entities for certain emergency services and the repair or replacement of disaster damaged public facilities.
- Hazard Mitigation Assistance: Funding for measures designed to reduce future losses to public and private property.

Some declarations will provide only individual assistance or only public assistance. The major Presidentially Declared Disasters and Emergency Declarations for New Hampshire from 1986 to 2012 are summarized in the figure below.

Figure 9.1.1- Federal Expenditures on Presidentially Declared Disasters and Emergency Declarations in New Hampshire from 1986 to 2012 (adjusted to 2012 dollars)¹



Strategies for Hazards and Emergency Preparedness

- Inventory and evaluate critical culverts, bridges, and dams to meet operational standards as determined by the local communities. Bridges should also be evaluated for ice jams. Develop replacement programs.
- Complete fluvial erosion hazard assessments for the Sugar, Mascoma, and Connecticut Rivers. Incorporate fluvial erosion into hazard mitigation plans to evaluate local susceptibility to riverine erosion and to identify homes and infrastructure at greatest risk from eroding or weakening stream banks.
- Evaluate municipal Master Plans, policies and regulations to determine if they assist or deter hazard mitigation efforts. (e.g. minimize further development in flood plains, protect steep slopes from overdevelopment and inappropriate logging operations, protect wetlands for flood absorption, and evaluate building codes for things like lashing of propane/gas tanks)
- Advocate for federal re-evaluation of FEMA floodplain mapping to make them more accurate for planning and development purposes. Consider other methods of accurate floodplain delineation.
- Encourage municipalities to participate in the National Flood Insurance Program and have up-to-date Hazard Mitigation Plans and Emergency Operations Plans.
- Identify priorities from the municipal Hazard Mitigation Plan and add needs for Emergency Management. Incorporate these items into the municipal Capital Improvement Program. Evaluate funding sources through FEMA and NH HSEM.
- Enforce 911 numbering system to assist emergency responders in locating properties.
- Provide ongoing educational opportunities to engage the public in the hazard mitigation and emergency management of the municipality. Teach how individuals, families, schools, and businesses can be prepared for an event.
- Work with schools as a team in emergency preparedness.

9.2 ADDRESSING CLIMATE CHANGE

Vision

The region will anticipate, prepare for, respond to and recover from climate change impacts in a way that minimizes significant disruption to communities including health, safety, built environments, food availability, natural resources, wildlife and financial strength.

Climate Change in the Region

While it is well understood that climate change is a naturally-occurring phenomenon, there is a growing body of scientific evidence indicating human activities are influencing the Earth's climate system.

As part of the Granite State Future project the state's regional planning commissions engaged Climate Solutions New England to prepare two regional studies addressing climate change for northern and southern New Hampshire. These reports describe how the climate of New Hampshire has changed over the past century and how the future climate of the region will be affected by a warmer planet due to human activities. The following information is a brief synopsis of the full report, *Climate Change in Southern New Hampshire*, which is included in Appendix III of this chapter.

Overall, southern New Hampshire has been getting warmer and wetter over the last century, and the rate of change has increased over the last four decades. Detailed analysis of data collected at three U.S. Historical Climatology Network meteorological stations in Keene, Durham, and Hanover reveals the following changes since 1970:

- Average annual maximum temperatures have warmed 1.1 to 2.6°F (depending on the station) with the greatest warming

occurring in winter (1.6 to 3.4°F).

- The number of days with minimum temperatures less than 32°F has decreased, and the coldest winter nights are warming.
- The length of the growing season is two to four weeks longer.
- Annual precipitation has increased 12 to 20 percent.
- Extreme precipitation events have increased across the region, which are evident in the several large floods that have occurred across New Hampshire over the last decade.
- The number of snow-covered days has decreased by twelve days in Hanover.
- More than a century of observations show that spring lake ice-out dates on Lake Sunapee are occurring ten to twenty days earlier today than in the past.

Future climate projections for southern New Hampshire simulated temperature and precipitation from four Global Climate Models and adjusted to New Hampshire using regional historical weather observations. These future climate projections followed two possible scenarios:

- Lower Emission Scenario: Global improvements in energy efficiency and development of renewable energy results in reduced emissions of heat-trapping greenhouse gases below 1990 by the end of the twenty-first century.
- Higher Emissions Scenario: Fossil fuels are assumed to remain a primary energy resource and emissions of heat-trapping greenhouse gases grow to three times those of today by the end of the century.

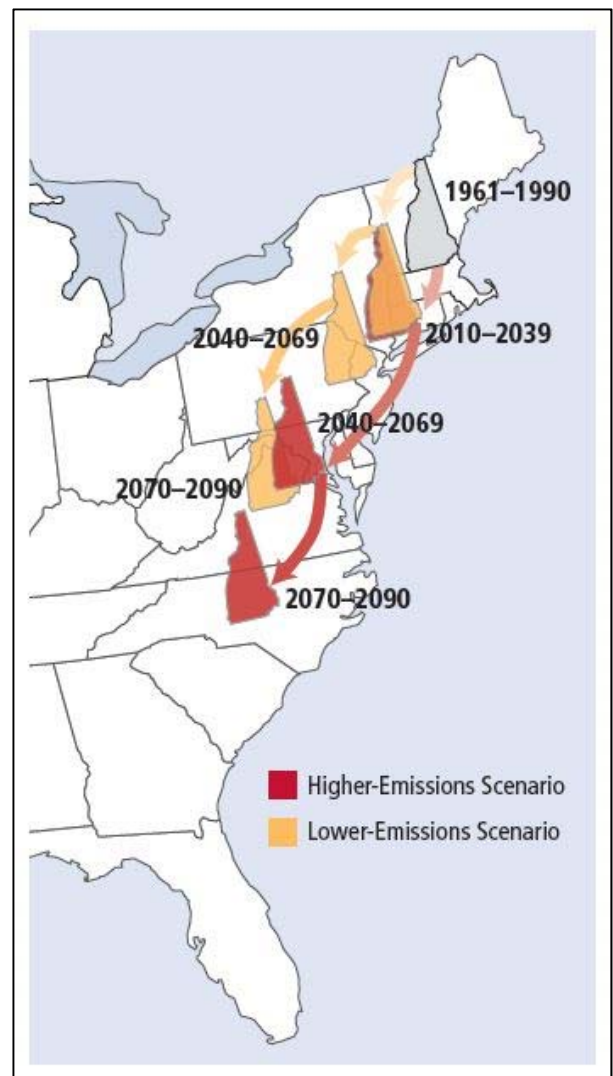
The report provides an overview of the likely climate-related outcomes under both

scenarios. The image to the right visually represents how summers are projected to feel under either scenario. Projected outcomes of the two climate change scenarios include:

- Mid-century annual average temperatures may increase 3 to 5°F, and end-of-century annual average temperatures may increase as much as 4 to 8°F.
- Average summer temperatures may be up to 11°F warmer under the higher emissions scenario (compared to the historical average from 1980 to 2009).
- The frequency of extreme heat days is projected to increase dramatically, and historically hot days will be even hotter.
- Extreme cold temperatures are projected to occur less frequently, and extreme cold days will be warmer than in the past.
- Annual average precipitation is projected to increase 17 to 20 percent by end-of-century.
- The frequency of extreme precipitation events may increase significantly. Under the high emissions scenario, storm events that drop more than four inches of precipitation in forty-eight hours are projected to increase two- to three-fold by the end of the century.

Observed changes in climate have correlated to significant impacts to New Hampshire's environment, ecosystems, economy, and society. The National Climate Assessment, released May 2014,³ identified seven societal and environmental sectors affected by climate change and reflected in this Regional Plan:

- Water resources;
- Human health;
- Energy supply and use;
- Transportation;
- Agriculture;
- Forests, and;
- Ecosystems and biodiversity.



*Above: Projected Summer Climate Shifts 2007
Northeast Climate Impacts Assessment, Union of
Concerned Scientists²*

Observed climate changes over the past several decades are already having a significant impact on New Hampshire.

- The impact of extreme, sustained heat on human health, infrastructure, and the electrical grid.
- Winter warming may reduce heating bills and the risk of cold-related accidents and injury. However, warming winters will reduce opportunities for snow and ice related recreation (and related economic activity).
- Winter warming would also allow some

pests and invasive species to enter the Region that have historically not survived winter temperatures. Winter warming would also affect the habitat and sustainability of New Hampshire's more cold-adapted native flora and fauna.

- The growing season will get longer, which may provide opportunities for farmers to grow new crops. Many existing crops will likely experience yield losses associated with increased frequency of high temperature stress, more frequent extreme weather events (e.g.: erosion from rain or plant damage from hail), inadequate winter chill period, and increased pressure from invasive weeds, insects, or disease.

Communities may respond to climate change by following two different approaches: mitigation or adaptation⁴ or a combination thereof.

Mitigation: The New Hampshire Climate Action Plan calls for the reduction of greenhouse gas emissions and provides an in-depth analysis of actions for local, regional and state agencies to reach the Plan's long-term goals: Reduce greenhouse gas emissions to 20 percent below 1990 emissions by 2025 and to 80 percent below 1990 emissions by 2050.⁶

Adaptation: Communities, businesses, and residents will need to prepare and plan for climate change to minimize the risks associated with natural disasters and extreme weather events. The increasing frequency and cost of damaging natural disasters as illustrated on Figure 9.1.1 on Page 9-5 makes a clear case that adaptation needs to be a regional priority

Adapting to Climate Change

Based on the findings of the climate change study in Appendix III it is not a question of if

climate change is happening, but rather a question of how badly the Region's communities will be affected. Severe weather events can have a significant impact on local and regional transportation, infrastructure, natural resources, and public health and safety. As they become more frequent and severe, communities will find increased pressure to adapt to the conditions, but the process for adaptation may not be the same from community to community.

Various adaption planning and implementation strategies can occur simultaneously as part of a broader process, which includes characterizing vulnerabilities, developing options, implementing actions, monitoring outcomes, and reevaluating strategies. Communities should discuss, analyze, and then determine which adaptation strategies to implement based on their specific vulnerabilities to climate change and local economic, environmental, and social conditions.⁷ While practicing adaptation will benefit a community's capacity to minimize the risk of a natural disaster, there needs to be a balance that considers overall community goals, economic, societal, and environmental needs as well as the benefits of the individual and collective actions.

Vulnerability Analysis: The *Sunapee Watershed Stormwater Infrastructure Project* (2012)⁵ used detailed watershed analyses and climate projections to assess drainage system vulnerability to development pressures and climate change. For the towns in the Lake Sunapee watershed, the study concluded that:

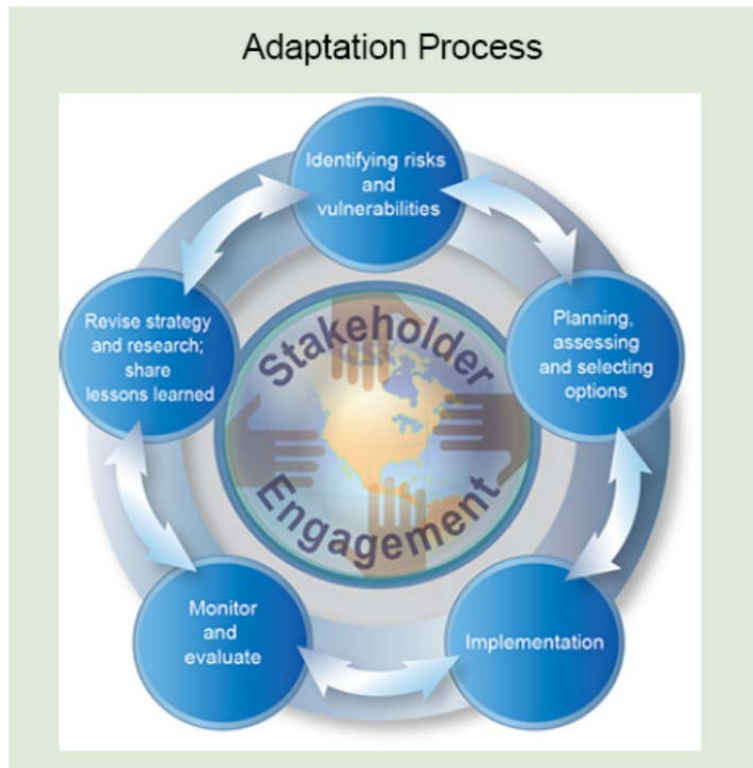
- *Under current conditions, 12% of culverts are undersized for a severe storm event.*
- *35% of culverts are expected to be undersized by mid-21st century for a similar storm event.*

The best effect this process will have is within existing local plans, policies, and practices that have been amended to address the vulnerabilities of the local community. Fortunately for New Hampshire communities, there are opportunities for adaptation available within existing planning and regulatory processes. Specific examples are available for reference in Appendix IV.

Efforts to address climate change should seek input, participation, and support from community members. This may be achieved through specific outreach to neighborhoods or interest groups, municipal meetings, or through larger community events.

As communities adopt various adaptation strategies they are encouraged to monitor their effectiveness. At the time of this Regional Plan there are limited methods of evaluation. Each community should include in its planning and implementation process consideration for measuring the success of the adaptation measure.

At the regional level, the UVLSRPC has strongly supported the continued development of the Upper Valley Adaptation Workgroup (UVAW). The UVAW is a bi-state, multi-stakeholder working group of local leaders, businesses, medical and educational institutions, and advocacy organizations. Started in December of 2011, the workgroup meets regularly focusing on the aim of building climate resilient communities in the



*Above: Generalized Adaptation Process
(Source: National Climate Assessment, 2014)*

Upper Valley Region of Vermont and New Hampshire.

The UVAW has held a series of well-attended local workshops focused on developing community and economic resiliency. UVLSRPC has provided staff and website support to the UVAW, and should continue to remain engaged in developing and growing this important workgroup.

Strategies for Climate Adaptation and Mitigation

- Support the local and regional implementation of mitigation strategies identified in the New Hampshire Climate Action Plan.
- Integrate planning for transportation, land use, human health, natural resources, and ecosystem services.
- Integrate zoning, land use, and resource conservation – environmental and floodplain regulation, conservation subdivision incentives in high-risk areas, village center zoning, transfer of development rights, open space, and land preservation.
- Support the continued development and growth of the Upper Valley Adaptation Workgroup (UVAW).
- Encourage Sustainability and Smart Growth planning- mixed use development and village development, conservation/open space subdivision, alternative transportation access, and preservation of agricultural lands.
- Assist communities in conducting regulatory audits to identify barriers and incentives to implement climate change planning and adaptation at the local level (zoning, regulations, and master plan).
- Encourage integration of climate change into local plans – master plans, hazard mitigation plans, open space/land conservation plans, and regional health assessments.
- Adopt long-range infrastructure investments and improvements into capital improvement plans (CIPs) and maintenance plans.
- Encourage municipal participation in the FEMA Community Rating System to reduce flood insurance premiums
- Encourage cooperative agreements among municipalities (e.g.: water and sewer services, equipment, staff, and integrated transportation, land use, and environmental planning).
- Develop a plan for regional implementation of recommended actions from the NH Climate Action Plan.
- Develop watershed-level plans to evaluate natural and constructed flood storage options upstream of existing areas of concentrated development that are at risk of flooding.
- Consider moving or discontinuing roads when damaged by repeated flood events prior to repairing in place.
- Encourage the Federal Emergency Management Agency (FEMA) to utilize current scientific projections of storm intensity and frequency in revisions to flood maps so that regulations are anticipating climate changes.
- Avoid constructing critical facilities and community assets in the 100-year flood zone unless elevated at least two feet above the base flood elevation and outside of erosion risk areas or hardened to withstand flood forces.

APPENDIX I- GLOSSARY OF HAZARDS

A “hazard” can be defined as a natural or human-caused threat that may result in an emergency or disaster with the potential to cause harm or other undesirable consequences. Natural and human-caused hazards occur in every municipality. In our region, the more common hazards municipalities address in their hazard mitigation planning include the following.

Flooding

Flooding is the inundation of normally dry land. Common impacts of flooding include damage to personal property, buildings, and infrastructure; bridge and road closures; service disruptions; and injuries or even fatalities.

Local Example: In 2005 in Acworth, the Cold River flooded in South Acworth village along Route 123A—the only numbered route in the town and a key east-west corridor for southern Sullivan County. More recently in June 2013, the Federal Emergency Management Agency declared a disaster in Grafton and Sullivan Counties for severe storms, flooding and landslides.

Dam Failures

Dam failures occur when a dam is breached and water flows uncontrolled through or over the dam.

Local Example: A dam does not have to be located in a particular town to affect it. The Moore Dam in Littleton, the Comerford Dam in Monroe, and the Wilder Dam in Wilder, VT impacts any town south of the dams along the Connecticut River. In 1996, the Cold Brook Pond Dam in Lempster had a progressive failure which caused complete erosion of the vegetated

emergency spillway.

Hurricanes and Tropical Storms

Hurricanes and tropical storms are violent storms with intense winds, heavy rain, a storm surge, floods, coastal erosion, landslides, and tornadoes. The season for hurricanes is June through November, with most hurricanes occurring mid-August to late October. The Saffir/Simpson scale is one scale to measure the intensity of the hurricane. While these weather events most significantly threaten coastal communities Tropical Storm Irene demonstrated how inland landscapes and communities can be affected.

Local Example: One of the most notorious hurricanes to occur in our region was the Hurricane of 1938, which hit New England and killed up to 800 people. In contrast, Hurricane Irene (and then Tropical Storm Irene) in 2011 killed 16 people, which is probably in large part due to our more recent warning systems and better preparedness.

Tornadoes and Downbursts

A tornado is a violently rotating column of air that has contact with the ground and is often visible as a funnel cloud. The destruction caused by tornadoes ranges from light to catastrophic depending on the intensity, size and duration of the storm. Typically, tornadoes cause the greatest damage to structures of light construction, including residential dwellings and particularly manufactured homes. Tornadoes are more likely to occur during the months of March through May and tend to form in the later afternoon and early evening.

Local Example: In April 2007, a major wind event damaged structures, power lines and trees in Lyme. A portion of the community was without power for several days.

Thunderstorms, Hail, Lightning

Hailstorms are potentially damaging outgrowths of severe thunderstorms, and can cause substantial damage to vehicles, structures, landscaping, and other areas of the built environment. Agriculture is often affected by hailstorms, which cause severe crop damage even during minor events. Lightning is a discharge of electrical energy that results from the buildup of positive and negative charges in a thunderstorm. On average, 55 people are killed and hundreds are injured each year by lightning strikes in the U.S. Lightning can strike communications equipment (e.g. radio or cell towers, antennae, satellite dishes, etc.) and hamper communication and emergency response. Lightning strikes can also cause significant damage to buildings, critical facilities, and infrastructure, often due to an electrical surge or igniting a fire. Lightning can also ignite a wildfire in remote, undeveloped areas.

Local Example: In Sunapee, there have been a few structure fires caused by lightning over the last several years. Lightning has caused damage to the water filtration plant electrical system on several occasions including a storm which caused substantial damage to office equipment. Fuses were installed to prevent future damage, and the fuses must be changed five to six times a year due to lightning. In addition, the nearby town offices received damage to their computer and radio equipment in 2004.

Severe Winter Weather

Severe winter storms may include snow, sleet, freezing rain, or a mix of these wintry forms of precipitation. Severe winter weather can down trees, cause widespread power outages, damage property, and cause fatalities and injuries.

Local Example: Severe winter weather is common in our region. There was a declared disaster for a severe winter storm as recent as February 2013. In 1998, an ice storm caused over \$3 billion worth of damage in the northeast and millions of people lost power – some for an extended period. This was an historic event because of its prolonged duration and the magnitude of ice accretion and precipitation amounts.

Earthquakes

Earthquakes occur with a sudden release of energy that creates movement in the earth's crust. Most earthquake-related property damage and deaths are caused by the failure and collapse of structures due to the ground shaking. The level of damage depends upon the extent and duration of the shaking. Other damaging earthquake effects include landslides, the down-slope movement of soil and rock (in mountain regions and along hillsides), and soil liquefaction

Local Example: In addition to tremors originating in the state, New Hampshire has experienced stronger earthquakes centered in the St. Lawrence seismic zone and in the northeastern Massachusetts seismic zone. A 1964 earthquake caused fallen plaster in Plainfield and other damage just outside the region. The largest earthquake was in 1940 and centered near Lake Ossipee. Most of the damage was very local although minor damage occurred for

some distance into several states and Quebec.

Landslides

Landslides are the movement of a mass of rock, debris, or earth down a slope by the force of gravity. Landslides occur when the slope or soil becomes unstable, which may be caused by earthquakes, storms, erosion, fire, or human-induced activities. Slopes greater than 10 degrees are more likely to slide, as are slopes where the height from the top of the slope to its toe is greater than 40 feet. Slopes are also more likely to fail if vegetative cover is low or soil water content is high. Potential impacts include environmental disturbance, property and infrastructure damage, and injuries or fatalities.

Local Example: In 1999, during Hurricane Floyd, a travel lane on the river side of the road collapsed leaving a hanging sewer line and unsupported guardrails along Bank Street Extension in Lebanon. More recently, Lebanon has experienced landslides between the north side of U.S. Route 4 and the Mascoma River, from the intersection of U.S. Route 4/NH Route 4A westerly.

Drought

Drought is a period of unusually constant dry weather that persists long enough to cause deficiencies in water supply—surface or underground. Droughts are slow-onset hazards, but over time, they can severely affect crops, municipal water supplies, recreational resources, and wildlife. If drought conditions extend over a number of years, the direct and indirect economic impacts can be significant. This can also make an area more susceptible to wildfire. Human actions and demands for water resources can accelerate drought-related impacts.

Local Example: Following the drought conditions experienced in New Hampshire in the early 2000s, the Hanover Water Company, owned by the town and Dartmouth College, adopted a drought mitigation plan to determine levels of restriction and enforcement in case of a drought.

Extreme Temperatures

Extreme temperatures of hot and cold can both occur in our region. Extreme heat can detrimentally affect people everywhere; the elderly and people who are obese are more likely to be affected by extreme heat than the rest of the population. Fatalities can result from extreme temperatures, as they can push the human body beyond its limits to hyperthermia and hypothermia. The homeless are especially vulnerable.

Local Example: The NH Department of Health and Human Services issues press releases to advise people to take precautions during extreme heat. One of these releases was issued in the summer of 2013. Tragically, local authorities discover individuals, often homeless, who have died from exposure.

Erosion

Erosion is the wearing-away of land, such as loss of riverbank or shoreline due to surface water influences. Periodic natural events cause erosion, such as flooding, but may be intensified by human activities. Long-term erosion is a result of multi-year impacts such as repetitive flooding, wave action, sediment loss, and increased perennial water flow. Death and injury are not typically associated with erosion, but it can damage buildings and infrastructure. Most flood damage in our area is caused by fluvial erosion (from streams and rivers) often affecting the transportation system.

Local Example: In 2005 and 2006, a bridge crossing a stream on Province Road in Dorchester was destroyed by fluvial erosion and flooding. The estimated cost at the time was almost a million dollars for replacement. There are several similar examples of flood damage throughout the region.

Wildfire

Wildfire is any outdoor fire that is not controlled, supervised, or arranged. Wildfire probability depends on local weather conditions; outdoor activities such as camping, debris burning, and construction; and the degree of public cooperation with fire prevention measures. Wildfires can result in widespread damage to property and loss of life.

Local Example: Wildfires are not as prevalent in the northeast due to our climate; however, when there has been a drought causing sufficient fuel for a fire, a careless act can cause a major wildfire. In 2005, Springfield had a fire in the Gile State Forest, which was contained by firefighters and only burned five acres.

Natural Contaminants

Natural contaminants such as radium, radon and uranium are naturally occurring radionuclides. These three particular substances are a health risk only if taken into the body by ingestion or inhalation. Radionuclides are undetectable by taste, odor, or color. Wells drilled into bedrock are more likely to contain elevated levels of radionuclides than shallow or dug wells. Radon gas can be found in the soil and can enter buildings through foundation cracks and penetrations where pipes enter. Testing well water or basement air quality can determine exposure to unsafe levels of radionuclides.

There are many other natural contaminants which can render drinking water unsafe such as arsenic. The Drinking Water and Groundwater Bureau of the NH Department of Environmental Services has several fact sheets available to address natural contaminants.

Local Example: Being the "Granite State," there are many cases of radionuclides contamination in homes and well water. Generally, this information is not shared with the municipality. When I-89 was being constructed, outcroppings of uranium were found which is not surprising since the Ruggles Mine in Grafton is a uranium mine. Uranium and other contaminants are found in our bedrock which can provide particles in our drinking water. NH DES says 40% or more of NH residents get their drinking water from private wells, and many of those wells have unhealthy levels of naturally-occurring arsenic, radon, or other contaminants.

Hazardous Materials

Hazardous materials spills are the release of any substance or material in a quantity or form which may be harmful to humans, animals, crops, water systems, or other elements of the environment. Hazardous materials include: explosives, gases (compressed, liquefied, or dissolved), flammable and combustible liquids, flammable solids or substances, oxidizing substances, poisonous and infectious substances, radioactive materials, and corrosives. The spill can occur from something as common as a home fuel delivery or it could be from a vehicle accident on the road.

Local Example: Hazardous materials spills may happen fairly frequently as they

include overflow spills when home heating fuel is delivered and delivery of gasoline to gas stations as well as transported hazardous materials along our highways.

Public Health

Public Health concerns include contamination to drinking water, infectious diseases like meningitis, and insect-borne diseases. Large gatherings are potential places where diseases could be transferred.

Local Example: This is a concern at colleges, where a diverse international student body lives together and can be easily exposed to and transmit diseases.

Terrorism

Terrorism has been defined in many ways. The word terrorism is derived from the Latin term "terrere" which means to frighten. Under current United States law, set forth in the US Patriot Act, acts of

domestic terrorism are those which: "(A) involve acts dangerous to human life that are a violation of the criminal laws of the United States or of any State; (B) appear to be intended— (i) to intimidate or coerce a civilian population; (ii) to influence the policy of a government by intimidation or coercion; or (iii) to affect the conduct of a government by mass destruction, assassination, or kidnapping; and (C) occur primarily within the territorial jurisdiction of the United States."

Local Example: In 1993, a disgruntled resident in Newbury opened fire on town employees killing two women. More recently shootings in and around schools have prompted the development of "lockdown" procedures to protect students and staff.

APPENDIX II- MUNICIPAL EMERGENCY COORDINATION TABLES

Municipal Mutual Aid Agreements in the UVLSRPC Region

Municipality	Fire	Public Works		
		Highway	Building Inspection	Waster and Wastewater
Acworth	SW	x		
Canaan	UV	x		
Charlestown	SW	x		
Claremont	SW,UV			
Cornish	UV			
Croydon	K			
Dorchester	UV, LR	x		
Enfield	UV	x	x	
Goshen	SW			
Grafton	UV	x		
Grantham	UV	x		
Hanover	UV	x		x
Lebanon	UV			
Lempster	SW	x		
Lyme	UV	x		
New London	K	x		x
Newbury	K	x		
Newport	K	x		x
Orange	UV			
Orford	UV	x		
Piermont	UV	x		
Plainfield	UV			
Springfield	K, UV	x		
Sunapee	K			x
Unity	SW			
Washington	SW, K	x		
Wilmot	K	x		

Note: There are several intermunicipal agreements for assistance that are not shown here, including agreements related to the acceptance of wastewater between municipalities.

K- Kearsarge Mutual Aid

LR – Lakes Regional Mutual Fire Aid Association

SW – Southwestern NH Mutual Aid & Dispatch

UV – Upper Valley Emergency Services Association

Municipal Dispatch Coordination in the UVLSRPC Region

Municipality	Dispatch			
	Fire	Police	EMS	Hwy
Acworth	SW	CH	SW	Local
Canaan	H	H	H	Local
Charlestown	SW	CH	CH	CH
Claremont	C	C	C	C
Cornish	H	C	H	Local
Croydon	NL	NL	NL	NL
Dorchester	H, LR	SPolice	H, LR	Local
Enfield	H	H	H	H
Goshen	SW	NL	SW	Local
Grafton	H	GCS	H	Local
Grantham	H	NEWP	NL	Local
Hanover	H	H	H	H
Lebanon	L	L	L	L
Lempster	SW	C	SW	Local
Lyme	H	H	H	H
New London	NL	NL	NL	NL
Newbury	NL	NL	NL	NL
Newport	NEWP	NEWP	NEWP	NEWP
Orange	H	GCS, SPolice	H	Local
Orford	H	H	H	H
Piermont	GCS	GCS	GCS	Local
Plainfield	H	H	H	Local
Springfield	H	NEWP	H	Local
Sunapee	NL	NL	NL	NL
Unity	SW	C	SW	Local
Washington	HPD	HPD	HPD	HPD
Wilmot	NL	NL	NL	NL

Note: There are several intermunicipal agreements for assistance that are not shown.

SW- Southwestern NH Mutual Aid & Dispatch

H – Hanover Dispatch

L – Lebanon Dispatch

LR – Lakes Regional Mutual Fire Aid Association

C – Claremont Dispatch

HPD – Hillsborough

CH – Charlestown Dispatch

NL – New London

GCS – Grafton County Sheriff Department

SPolice – State Police

Hazard Mitigation Plan Status in the UVLSRPC Region

Town	NFIP Participant	Fluvial Erosion Element Required	Next Five-year Update Due to FEMA
Acworth	Y		4/1/2018
Canaan	Y		5/24/2016
Charlestown	Y		In process
Claremont	Y	Y	4/13/2016
Cornish	Y	Y	7/13/2016
Croydon	N		Never done
Dorchester	Y		2019
Enfield	Y		In process
Goshen	Y	Y	In process
Grafton	N		Never done
Grantham	Y	Y	In process
Hanover	Y		In process
Lebanon	Y		7/13/2016
Lempster	N		In process
Lyme	Y		2016
New London	Y		2/4/2018
Newbury	Y		5/16/2017
Newport	Y	Y	6/21/2015
Orange	N		5/26/2016
Orford	Y		2015
Piermont	Y		2/3/2017
Plainfield	Y		2015
Springfield	Y		5/18/2018
Sunapee	Y	Y	In process
Unity	Y		10/7/2019
Washington	Y		6/10/2015
Wilmot	Y		2018

APPENDIX III- CLIMATE CHANGE IN SOUTHERN NEW HAMPSHIRE

Climate Change in Southern New Hampshire

PAST, PRESENT, AND FUTURE

A PUBLICATION OF THE SUSTAINABILITY INSTITUTE AT THE UNIVERSITY OF NEW HAMPSHIRE





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Climate Change in Southern New Hampshire

PAST, PRESENT, AND FUTURE

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EXECUTIVE SUMMARY

EARTH'S CLIMATE CHANGES. It always has and always will. However, an extensive and growing body of scientific evidence indicates that human activities—including the burning of fossil fuel (coal, oil, and natural gas) for energy, clearing of forested lands for agriculture, and raising livestock—are now the primary force driving change in the Earth's climate system. This report describes how the climate of southern New Hampshire has changed over the past century and how the future climate of the region will be affected by a warmer planet due to human activities.

Overall, southern New Hampshire has been getting warmer and wetter over the last century, and the rate of change has increased over the last four decades. Detailed analysis of data collected at three U.S. Historical Climatology Network meteorological stations (Keene, Durham, and Hanover) show that, since 1970:

- Average annual maximum temperatures have warmed 1.1 to 2.6°F (depending on the station) with the greatest warming occurring in winter (1.6 to 3.4°F).
- The number of days with minimum temperatures less than 32°F has decreased, and the coldest winter nights are warming.
- The length of the growing season is two to four weeks longer.
- Annual precipitation has increased 12 to 20 percent.
- Extreme precipitation events have increased across the region; this increase has been dramatic at some sites in southern New Hampshire. The impact of this increase in large precipitation events is evident in the several large floods that have occurred across New Hampshire over the last decade.
- The number of snow-covered days has decreased by twenty-seven days in Durham and twelve days in Hanover.

In addition, more than a century of observations shows that spring lake ice-out dates on Lake

Winnepesaukee and Lake Sunapee are occurring ten to twenty days earlier today than in the past.

To generate future climate projections for southern New Hampshire, simulated temperature and precipitation from four Global Climate Models (GCMs) were statistically downscaled using historical weather observations. We accounted for a range of potential future fossil fuel use by using two very different future global emission scenarios. In the lower emissions scenario, improvements in energy efficiency, combined with the development of renewable energy, reduce global emissions of heat-trapping gases (also known as greenhouse gases) below 1990 levels by the end of the twenty-first century. In the higher emissions scenario, fossil fuels are assumed to remain a primary energy resource, and emissions of heat-trapping gases grow to three times those of today by the end of the century. Although both scenarios are possible, the current global emissions trend from 2000 through 2012 suggests that, in the absence of concerted international efforts to reduce emissions, climate change will likely track or exceed that projected under the higher emissions scenario over the course of this century.

As heat-trapping gases continue to accumulate in the atmosphere, temperatures will rise in southern

New Hampshire. Depending on the emissions scenario, mid-century annual average temperatures may increase on average by 3 to 5°F, and end-of-century annual average temperatures may increase as much as 4°F under a lower to 8°F under a higher emission scenario. Summer temperatures may experience the most dramatic change, up to 11°F warmer under the higher emissions scenario compared to the historical average from 1980 to 2009. The frequency of extreme heat days is projected to increase dramatically, and the hottest days will be hotter, raising concerns regarding the impact of extreme, sustained heat on human health, infrastructure, and the electrical grid.

Extreme cold temperatures are projected to occur less frequently, and extreme cold days will be warmer than in the past. Winter warming may reduce heating bills and the risk of cold-related accidents and injury. However, warming winters will reduce opportunities for snow and ice related recreation (and related economic activity). Winter warming would also reduce cold temperature constraints that currently limit the spatial extent of some marginally over-wintering pests and invasive species.

The growing season will get longer, which may provide opportunities for farmers to grow new crops. However, many existing crops will likely experience yield losses associated with increased frequency of high temperature stress, an increase in soil erosion and crop failure resulting from more frequent extreme precipitation events, inadequate winter chill period for optimum fruiting, and increased pressure from invasive weeds, insects, or disease.

Annual average precipitation is projected to increase 17 to 20 percent by end-of-century. Larger increases are expected for winter and spring, exacerbating concerns regarding rapid snowmelt, high peak stream flows, and flood risk. Southern New Hampshire can also expect to experience more extreme precipitation events in the future. For example, under the high emissions scenario, events that drop more than four inches of precipitation in forty-eight hours are projected to increase two- to three-fold across much of southern New Hampshire by the end of the century.

Observed changes in climate over the past several decades are already having a significant impact on New Hampshire. The projected changes in the climate of southern New Hampshire over the next century will continue to impact our environment, ecosystems services, economy, and society in a myriad of ways. Because some future changes are inevitable, smart choices must be made to help our society and our ecosystems adapt to the new climate normal. With prompt action that improves the efficiency with which we use energy and significantly enhances sources of renewable energy, many of the most extreme consequences of climate change can be avoided and their worst impacts reduced. Our hope is that the focused information presented in this report provides local and regional stakeholders with relevant input for decision-making, serving as a foundation for the development of local and regional climate change adaptation plans, as well as regional mitigation plans to reduce emissions of heat-trapping gases.

I. INTRODUCTION

“Climate change is occurring, is very likely caused by human activities, and poses significant risks for a broad range of human and natural systems. Each additional ton of greenhouse gases emitted commits us to further change and greater risks.”¹

Over most of Earth’s 4.5 billion year history, large-scale climate variations were driven by natural causes including gradual shifts in the Earth’s orbital cycles, variations in solar output, changes in the location and height of continents, meteorite impacts, volcanic eruptions, and natural variations in the amount of greenhouse gases in the atmosphere.² Today, however, the story is noticeably different. Since the Industrial Revolution, atmospheric concentrations of heat-trapping gases, or greenhouse gases, such as carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) have been rising as a result of increasing emissions from human activities.³ The primary source of CO₂ comes from the burning of fossil fuels such as coal, oil, and natural gas. Carbon dioxide is also produced by land use changes, including tropical deforestation. Agricultural activity and waste treatment are critical sources of CH₄ and N₂O emissions. Atmospheric particles released during fossil fuel combustion, such as soot and sulfates, also affect climate.

As human-derived emissions of heat-trapping gases continue to rise, analysis of data collected around the globe clearly documents ongoing and increasingly dramatic changes in our climate system. These changes include increases in global atmospheric and ocean temperatures, atmospheric water vapor, precipitation and extreme precipitation events, and sea levels. They also include reductions in the volume and areal extent of spring and summer Arctic sea ice, reductions in

northern hemisphere snowcover, melting of mountain glaciers, increases in the flux of ice from the Greenland and West Antarctic ice sheets into the ocean, and thawing permafrost and methane hydrates.⁴ Detailed reviews of the extensive body of evidence from peer-reviewed climate science publications conclude that it is extremely likely that the majority of warming observed over the last fifty years have been caused by emissions of heat-trapping gases derived from human activities.⁵

The northeast United States has already experienced an overall warming over the past century, with an increase in the rate of warming over the past four decades. This change in our regional climate has been documented in a wide range of indicators, including increases in temperature (especially in winter), in overall precipitation, in the number of extreme precipitation events, and in the proportion of winter precipitation falling as rain (as opposed to snow). Observed changes also include a decrease in snow cover days, earlier ice-out dates, earlier spring runoff, earlier spring bloom dates for lilacs, longer growing seasons, and rising sea levels.⁶

To examine how climate change might impact our region in the future, we used scenarios of future emissions of heat-trapping gases as input to global climate models (GCMs). However, GCMs operate on the scale of hundreds of miles, too large to resolve the changes over southern New Hampshire. For that reason we used state-of-the-art statistical techniques to

downscale the regional temperature and precipitation simulations generated by the GCMs to observed conditions at individual weather stations across southern New Hampshire.⁷ The results show that, over the coming century, southern New Hampshire's climate is expected to continue to become warmer and wetter in response to increasing emissions of heat-trapping gases from human activities. The implications for southern New Hampshire are significant: hotter summers and warmer winters, more invasive pests and weeds, and an increase in precipitation and the frequency of extreme precipitation events. All of these impacts are greater under a higher emissions scenario versus a lower emissions scenario, and by the end of the century as compared to earlier time periods.

These changes will have repercussions on the region's environment, ecosystem services, economy, and society. A detailed analysis of the impacts of climate change on specific natural resources and other sectors (including forests, agriculture, recreation, water resources, human health, and invasive pests) is beyond the scope of this climate assessment. Fortunately, there is a wealth of analysis on the potential impacts of climate change across New England and the northeast United States in the peer-reviewed scientific literature.⁸ For example, warmer temperatures affect the types of trees, plants, and crops likely to grow in the area but will also allow an expansion of invasive pests and weeds. Long periods of very hot conditions in the summer are likely to increase demands on electricity and water resources. Hot summer weather can also have damaging effects on agriculture, human and ecosystem health, and outdoor recreational opportunities. Less frequent extreme cold in the winter will likely lower heating bills and reduce cold-related injury and death, but rising minimum temperatures in winter will likely open the door to invasion of cold-intolerant pests that prey on the region's forests and crops. Warmer winters will also have an impact on a wide range of

snow and ice related winter recreation.⁹ More extreme precipitation events, combined with an expansion of impervious surface associated with development, will increase the risk for both the frequency and magnitude of flooding.

In addition to the changes described above and in the body of this report, Earth's climate history, as read through the analysis of natural archives, including ocean sediments, ice cores, and tree rings, reveals several "tipping points"—thresholds beyond which major and rapid changes occur that can lead to abrupt changes in the climate system.¹⁰ The current rate of emissions of heat trapping gases is changing the climate system at an accelerating pace, making the chances of crossing tipping points more likely. There is a growing recognition that gradually changing climate can push both natural systems and human systems across key tipping points. However, accurately predicting if and when these tipping points will be crossed has proven challenging. Because of this uncertainty, the potential impact of crossing these tipping points is not discussed in detail in this report. However, the potential to cross key tipping points in the climate system should, where feasible, be integrated into our decision-making processes.

If we respond regionally and globally to the grand challenge of significantly reducing our emission of heat-trapping gases (this is called mitigation), we can avoid the more catastrophic climate change. And if we begin to plan locally and regionally for the unavoidable climate change that we have already baked into the climate system over the next several decades, we can adapt and avoid, manage, or reduce the consequences of our changing climate. This is called adaptation. Both mitigation and adaptation are necessary components of a sustainable future. We must reduce the impact we are having on climate, and we must prepare to adapt to the changes that are already underway.

The research and writing of this report, and a companion report for northern New Hampshire,

were completed with support from the Granite State Future project (Sidebar). For this report, we define meteorological stations located south of 43.90°N latitude as falling within southern New Hampshire (Figure 1). This is north of Lake Winnepesaukee but south of the notches. For the climate assessment for northern New Hampshire, we define meteorological stations located north of 43.75°N latitude as falling within northern New Hampshire. This provides an overlap of 0.15 degrees latitude, or about seventeen miles. Communities that lie within this overlap (for example, Plymouth, West Rumney, and Tamworth) can use either report. In addition, there is site-specific climate information provided in the climate grids (Appendix B) which contain historical and projected future thirty-year climatologies for twenty-five Global Historical Climatology Network-Daily (GHCN-Daily) meteorological stations across southern New Hampshire for the historical period (1980–2009) and the future (2010–2039, 2040–2069, 2070–2099).

Other New Hampshire-specific reports provide additional information and analysis beyond what is contained in this report. A climate assessment for New Hampshire's coastal watershed, which includes detailed analysis of sea level rise and coastal flooding, was published in 2011.¹¹ Under the leadership of the Department of Environmental Services, New Hampshire completed a detailed Climate Action Plan in 2009.¹² New Hampshire Fish and Game has recently updated its Wildlife Plan to include an Ecosystems and Wildlife Climate Adaptation Plan.¹³ The New Hampshire Department of Health and Human Services is currently developing an assessment and adaptation plan to respond to the public health impacts of climate change using the Center for Disease Control's BRACE framework (Building Resilience Against Climate Effects).¹⁴ There is also a statewide project funded by the National Science Foundation—Experimental Program to Stimulate Competitive Research

GRANITE STATE FUTURE¹⁶



Granite State Future is a project of the nine New Hampshire regional planning commissions (RPCs) to update regional plans. Formed by municipalities in the late 1960s and 1970s, the RPCs are mandated to undertake technical studies and develop comprehensive plans for their regions. In 2011, the RPCs jointly applied for and were awarded a U.S. Housing and Urban Development—Sustainable Communities Regional Planning Grant to carry out their legislated duty, believing that a coordinated effort would be a more efficient use of resources. Throughout the state, regions and localities are facing difficult decisions about investments in the future. Decision makers often have to prioritize and make tough choices. The nine regional plans will provide a concise story of what the citizens and communities in each region value, what they want for the future, and their ideas for getting there. The regional plans will be supplemented with a robust suite of statewide research, including climate assessments for northern and southern New Hampshire. These regional stories will be accompanied by technical analyses including: regional housing needs and fair housing and equity assessment, transportation, economic development, environment, water infrastructure, climate change impacts assessments, energy efficiency and green building, and other issues identified by the regions.

(EPSCoR)—that is studying the interactions among climate, land use, ecosystem services, and society.¹⁵ Many additional resources are referenced in Chapter IV.

II. HISTORICAL CLIMATE CHANGE

“Global climate is changing now and this change is apparent across a wide range of observations. Much of the climate change of the past fifty years is due primarily to human activities.”¹⁷

Annual and Seasonal Temperature Trends

Annual and seasonal minimum and maximum temperatures have been increasing across southern New Hampshire over the past one hundred years, and the rate of warming has increased over the past four decades. The largest temperature increases over the past four decades have occurred in winter.

Temperature is one of the most commonly used indicators of climate change. Today, temperatures have risen as a result of increased emission of heat-trapping gases from human activities and will likely continue to rise across southern New Hampshire over the foreseeable future. The temperature records from three long-term United States Historical Climatology Network (USHCN)¹⁸ meteorological stations in southern New Hampshire (Keene, Durham,¹⁹ and Hanover; Figure 1) provide a continuous record of temperature change for the last century in southern New Hampshire. A detailed description of the sources of high-quality meteorological data used in this report, quality control procedures, and statistical methods used to quantify historical trends in climate across southern New Hampshire and assess the statistical significance of those trends are described in detail in Appendix A.

Long-Term Temperature Trends: 1895–2012

All three weather stations show long-term temperatures increases over the period of record;

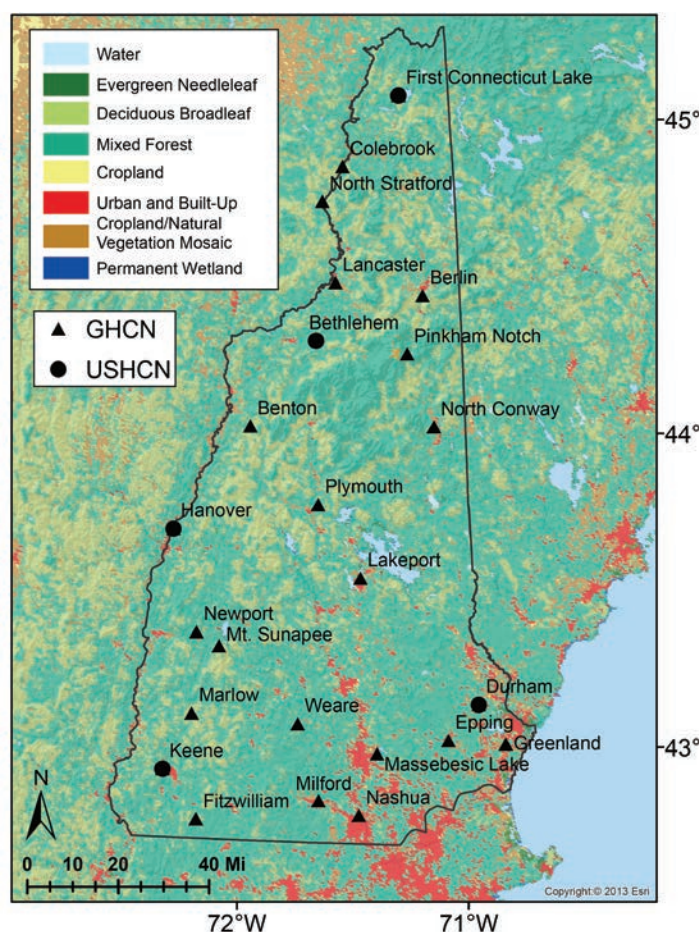


FIGURE 1. Map of New Hampshire showing land cover and the location of United States Historical Climate Network (USHCN) stations (black triangles) and Global Historical Climatology Network-Daily (GHCN) stations. For this report, the USHCN stations are the source of historical climate data in New Hampshire over the time period 1895–2012, while the GHCN-Daily stations are the source of data since 1960. For this report we define southern New Hampshire as all those meteorological stations that are south 43.90°N latitude.

increases in minimum temperatures are generally greater compared to increases in maximum temperatures (Figures 2 and 3). As is common in New England, significant year-to-year variability is evident at all three stations. Cool temperatures dominate the first half of the twentieth century, followed by a warm period in the 1940s to 1950s (more evident in maximum than minimum temperatures). Temperatures cool slightly through the 1960s and 1970s (again, a more dominant trend in maximum temperatures), followed by the current warm period of increasing temperatures from 1970 to the present. Despite these decadal-scale variations, all stations show consistent long-term increases in both minimum and maximum temperatures. Overall, more than half of the warmest years in terms of average annual maximum temperatures have occurred since 1990, and 80 percent or greater of the warmest years in terms of average annual minimum temperatures have occurred since 1990.

Recent Temperature Trends: 1970–2009

We also analyzed temperature trends for the same three stations over the last forty-three years, 1970–2012 (Table 1). This period coincides with a marked increase observed in global temperatures as a result of human activities, and also defines what

CLIMATE VERSUS WEATHER

“Climate is what we expect. Weather is what we get.”

—ROBERT HEINLEIN

Weather refers to the hourly and daily changes in local conditions, such as temperature, precipitation, humidity, and wind. Climate is the long-term average of these indicators. Climate normals are often expressed as thirty-year averages of climatological variables, including temperature, precipitation, and growing degree days. Because climate is a long-term average, shifts in climate are harder to observe than changes in weather. However, by tracking temperature and precipitation trends and patterns over long periods of time (decades to centuries) and in response to changing atmospheric conditions—such as rising concentrations of heat-trapping gases or changes in solar output or volcanic eruptions—researchers can identify long-term patterns in climate as distinct from day-to-day weather patterns. In other words, even if we are in the middle of a record cold snap this week (that’s weather), long-term temperature can still be rising (that’s climate).

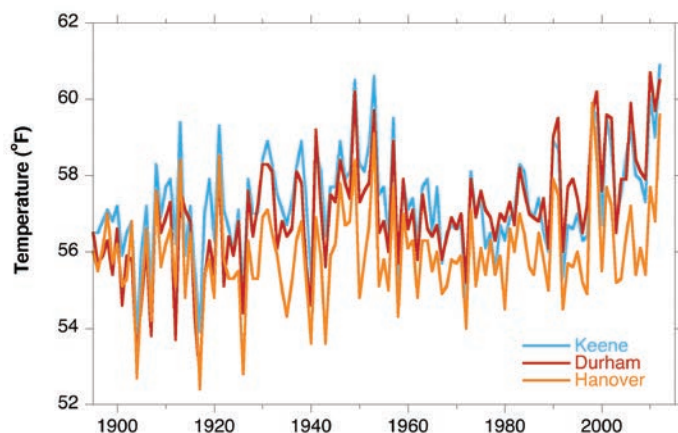


FIGURE 2. Annual *maximum* temperature records for USHCN stations in southern New Hampshire for the period 1895–2012.

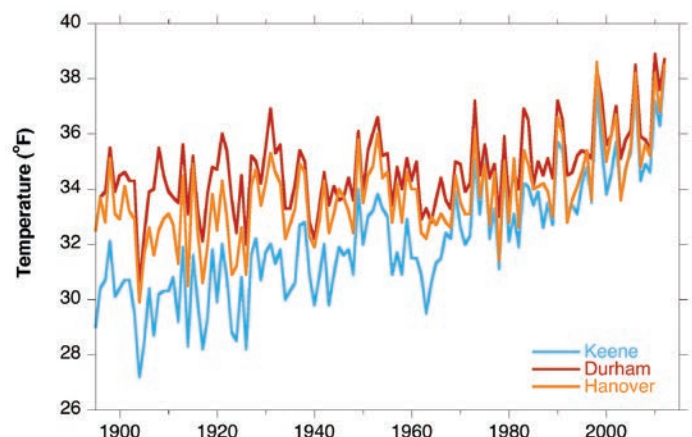


FIGURE 3. Annual *minimum* temperature records for USHCN stations in southern New Hampshire for the period 1895–2012.

we would consider “typical” climate today. Over the more recent time period, all three USHCN stations show significant warming trends in annual and most seasonal temperatures (for maximum temperature, Durham shows significant warming trends in annual and seasonal maximum temperatures, while significant maximum temperature trends are fewer in the Keene and Hanover records). These trends are much higher for both annual and seasonal temperatures relative to the long-term 1895–2012 rates of warming, consistent with the greater increase in global temperature over the same time period.

At the seasonal level, there is a dramatic increase in the rate of winter warming, which surpasses all other seasonal rates of warming over the last four decades at all three stations for both minimum and maximum temperatures. The rate of warming in Durham winter maximum and minimum temperatures over the past four decades increased by a factor of four relative to the 1895–2012 trend. The large increases in winter temperature may be linked to decreasing snow cover (see discussion below) through changes in surface albedo, or reflectivity.

Parameter	Durham		Keene		Hanover	
	1895–2012	1970–2012	1895–2012	1970–2012	1895–2012	1970–2012
TMAX (°F per decade)						
Annual	<u>0.21</u>	<u>0.55</u>	<u>0.09</u>	<u>0.61</u>	0.05	0.25
Winter	<u>0.20</u>	<u>0.80</u>	0.10	<u>0.71</u>	0.08	0.37
Spring	<u>0.32</u>	<u>0.72</u>	0.10	0.58	<u>0.15</u>	0.29
Summer	<u>0.27</u>	<u>0.47</u>	<u>0.12</u>	0.35	0.08	-0.05
Fall	<u>0.11</u>	<u>0.48</u>	0.04	<u>0.68</u>	-0.05	<u>0.60</u>
TMIN (°F per decade)						
Annual	<u>0.20</u>	<u>0.58</u>	<u>0.50</u>	<u>0.82</u>	<u>0.25</u>	<u>0.74</u>
Winter	<u>0.28</u>	<u>0.93</u>	<u>0.58</u>	<u>1.70</u>	<u>0.36</u>	<u>1.45</u>
Spring	<u>0.18</u>	0.24	<u>0.45</u>	0.31	<u>0.23</u>	<u>0.60</u>
Summer	<u>0.25</u>	<u>0.71</u>	<u>0.49</u>	<u>0.47</u>	<u>0.27</u>	<u>0.60</u>
Fall	<u>0.14</u>	<u>0.83</u>	<u>0.50</u>	<u>1.11</u>	<u>0.22</u>	<u>0.61</u>
Growing Season (Days per decade)						
	NA	10.0	NA	2.8	NA	5.9
Precipitation (inches per decade)						
Annual	<u>0.56</u>	1.63	0.32	2.02	0.26	1.16
Winter	-0.03	-0.61	0.45	0.16	0.37	-0.11
Spring	0.08	0.20	0.21	0.14	0.20	0.22
Summer	0.14	<u>0.93</u>	0.31	0.57	0.27	0.55
Fall	<u>0.27</u>	0.26	0.32	1.12	0.24	0.19
Snowfall	NA	<u>-9.14</u>	NA	0.34	NA	-3.44
Snow Covered Days (days per decade)						
Winter	NA	<u>-6.6</u>	NA	0.0	NA	-2.9
NA means data not available						

TABLE 1. Annual and seasonal trends in temperature, precipitation, and snow-covered days for the period 1895–2012 and 1970–2012 for three USHCN stations located in southern New Hampshire. Trends were estimated using Sen’s slope; trends that meet the Mann-Kendall non-parametric test for statistical significance ($p < 0.05$) are highlighted in **bold and underlined**.

Extreme Temperature Trends

While the number of hot days has increased only slightly across southern New Hampshire since 1960, the number of cold days has decreased and temperature on the coldest day of the year has increased significantly, reflecting the greater warming the region has experienced during the winter compared to other seasons.

Trends in annual and seasonal temperature may be too subtle for individuals to detect from personal experience. However, temperature extremes may provide more obvious evidence of warming. Changes in the distribution of both hot and cold extreme temperatures can lead to increased duration, frequency, and intensity of heat waves,²¹ lengthening of the growing season, and northward expansion of invasive insects like the woolly adelgid (*Adelges tsugae*), an aphid-like insect that has decimated stands of eastern hemlock from Georgia to Connecticut since the 1950s²² and ticks that carry Lyme disease.²³ Increasing trends in minimum daily temperature are indicators of nighttime warming, while trends in maximum daily temperature provide insight to daytime processes.

Daily temperature records are available back to 1960 for Durham, Hanover, Keene, and Nashua from the Global Historical Climatology Network-Daily (GHCN-Daily)²⁴; these daily temperature records have been homogenized.²⁵ In this analysis, we use a suite of simple indicators for tracking changes in temperature extremes over the period 1960–2102 (Table 2), consisting of trends in the: (1) number of “hot days” per year warmer than 90°F, (2) number of “cold days” per year colder than 32°F, (3) maximum temperature on the hottest days of the year, and (4) minimum temperature on the coldest day of the year. These four indicators of extreme temperature were analyzed for the period 1960–2012 as that is the longest period for which consistent daily records are available for the four stations analyzed here.

Location	Days > 90°F		TMAX(°F) Hottest Day of Year	
	1960-2012 average	Trend (days/decade)	1960-2012 average	Trend (°F/decade)
Hanover	6.0	0.1	94.4	0.0
Durham	8.3	0.8	95.0	0.0
Keene	7.5	0.0	94.9	0.0
Nashua	7.7	0.7	95.1	0.0

Location	Days < 32°F		TMIN(°F) Coldest Day of Year	
	1960-2012 average	Trend (days/decade)	1960-2012 average	Trend (°F/decade)
Hanover	151	<u>-3.8</u>	-18.9	<u>1.3</u>
Durham	150	<u>-5.0</u>	-14.5	<u>1.9</u>
Keene	158	0.50	-16.8	<u>2.2</u>
Nashua	154	<u>-5.0</u>	-12.1	<u>2.6</u>

TABLE 2. Extreme temperature trends for four GHCN-Daily stations in southern New Hampshire for the period 1960–2012. Trends are estimated using Sen’s slope; statistically significant trends ($p < 0.05$) are highlighted in **bold and underlined**.

The number of hot days has increased slightly over the last five decades in Durham and Nashua (+0.8 and +0.7 days per decade, respectively), while the maximum temperature on the hottest day of the year shows no trend. Conversely, there is a significant reduction in the number of cold days in Hanover (-3.8 days per decade), and Durham and Nashua (-5.0 days per decade for both sites). The minimum temperature on the coldest day of the year at all four stations has also shown a significant warming of +1.3 to +2.6°F per decade, consistent with the much greater warming in winter temperature compared to other seasons.

Length of the Growing Season

Since 1960, the length of the growing season in southern New Hampshire has increased by fifteen to fifty-two days.

While freezing temperatures affect all commercial, agricultural, industrial, recreational, and ecological systems, the human system most sensitive to changes in the length of the growing season is agriculture.²⁶

The length of the growing season is defined as the number of days between the last frost of spring and the first frost of winter. For our analysis, we have used a threshold of 28°F for a hard frost. This period is called the growing season because it roughly marks the period during which plants, especially agricultural crops, grow most successfully. A late spring or early fall hard frost may lead to crop failure and economic misfortune for the farmer. Earlier starts to the growing season may provide an opportunity to diversify crops and create new opportunities for farmers with sufficient capital to take risks on new crops. A longer growing season may also result in increased frequency of heat stress, inadequate winter chill period, and increased pressure from invasive weeds, pests, or disease.

While it might seem that switching to alternative warm-season crops represents a beneficial response to a longer growing season, farmers would then have new competitors who might have advantages such as better soils and a yet longer growing season.²⁷ It is possible that a significant change in the length of the growing season could alter the ecology of the landscape across New Hampshire, including an increase in transpiration (release of water vapor from plants) and a consequent decrease in soil moisture,²⁸ perhaps necessitating more use of irrigation.

The length of the growing season has been getting longer across southern New Hampshire (Figure 4), with a significant increase of +5.9 days per decade in Hanover, and +10.0 days per decade in Durham and Nashua (Table 3). The length of the growing season also increased in Keene, although the trend is not significant.

The impact of the increase in temperatures across New England is also documented by the changes in USDA plant hardiness zones, defined as the average annual minimum winter temperature, divided into 10°F zones.²⁹ As winter temperatures have risen over

the past several decades (Table 1), an update of the 1990 USDA hardiness zone map in 2006 revealed a northward shift in hardiness zones, with approximately one-third of New Hampshire shifting to a warmer zone.³⁰ Across the northeast, lilacs, apples, and grapes also show earlier bloom dates, consistent with the warming trend across the region.³¹

Annual and Seasonal Precipitation Trends

Annual precipitation has increased slightly over the past century. However, over the past four decades, the rate of the increase is two to three times greater than the long-term average.

Temperature and precipitation trends are linked in the Earth’s climate system by the hydrological cycle

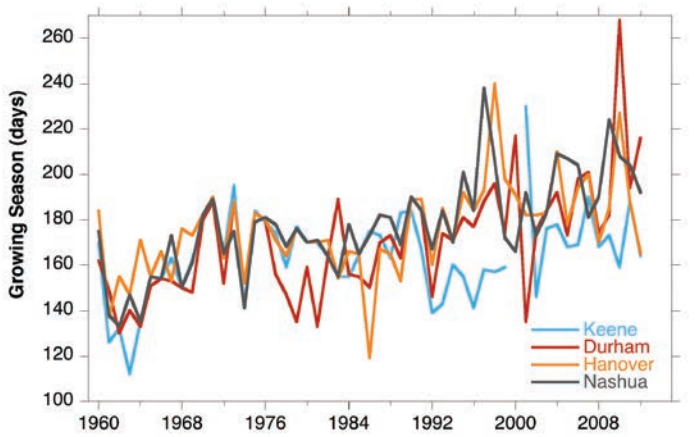


FIGURE 4. Length of the growing season for four GHCN-Daily stations in southern New Hampshire, 1960–2012.

Location	Growing Season	
	1960–2012 mean (days)	Trend (days/decade)
Hanover	175.9	<u>5.9</u>
Durham	170.4	<u>10.0</u>
Keene	164.4	2.8
Nashua	177.2	<u>10.0</u>

TABLE 3. Length of growing season for four GHCN-Daily stations in southern New Hampshire for the period 1960–2012. Trends are estimated using Sen’s slope; statistically significant trends (p<0.05) are highlighted in **bold and underlined**.

(Figure 5). Increases in precipitation may accompany increases in temperature because warmer air masses can hold more moisture. Regions with abundant moisture sources, such as New England, can therefore expect to see increases in the total amount and intensity of precipitation as temperatures continue to rise.³²

Long-Term Precipitation Trends: 1895–2009

The USHCN historical precipitation records have undergone rigorous quality checks for outliers and missing values.³³ Over the period 1895–2012, all three stations in the region exhibited modest increasing trends in annual precipitation (Figure 6; Table 1). In Durham, annual precipitation increased at a statistically significant rate of +0.56 inches/decade, or +6.7 inches over the past 118 years, an increase of about 8 percent. Keene experienced an increase of +0.32 inches per decade, and Hanover +0.26 inches per decade, although neither trend was significant at the 95 percent level ($p < 0.05$). Durham shows the greatest seasonal increase during the fall, while the largest trends at Keene and Hanover occur during the winter. All three sites also show a consistent record of low precipitation during the mid-1960s, indicative of the region-wide drought that occurred at that time (Figure 6; also see Sidebar on following page).

Recent Precipitation Trends: 1970–2012

Since 1970, all three stations show an increase in annual precipitation, although none were found to be statistically significant (Table 1). The rate of increase in annual precipitation from 1970–2012 is double to triple the long-term (1895–2012) increase. These increasing trends in precipitation are being driven by higher than average precipitation totals from 2005 to 2011. For example, the Mother's Day storm of May 13–16, 2006 (10.3 inches in four days in Durham) and the April 16, 2007 Patriot's Day storm (4.5 inches in one day in

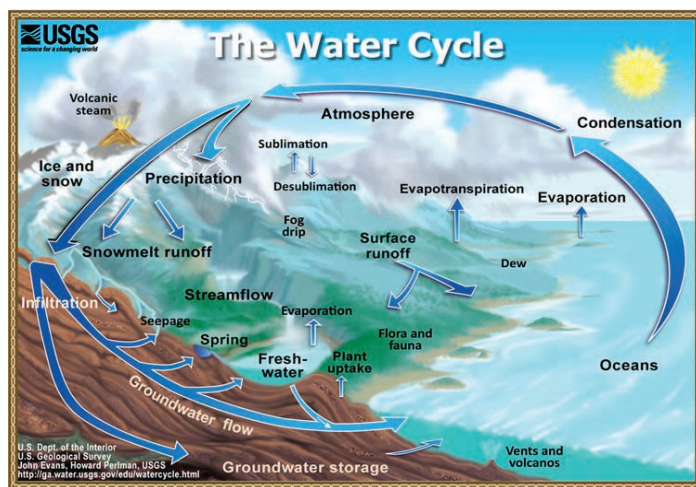


FIGURE 5. A schematic representation of Earth's water cycle that depicts the movement of water among key reservoirs (the oceans, atmosphere, snow and ice, lakes, groundwater) via key water cycle processes (evaporation, condensation, precipitation, transpiration, runoff, infiltration). Image from US Geological Survey (USGS). More information on the Earth's water cycle available online at: <http://ga.water.usgs.gov/edu/watercycle.html>

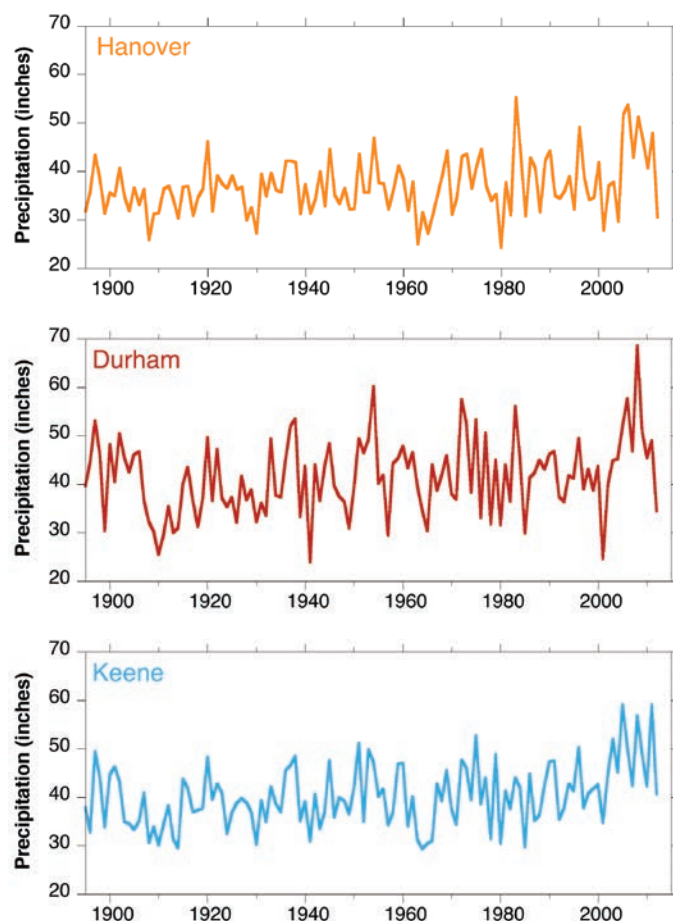


FIGURE 6. Annual precipitation records for USHCN stations in southern New Hampshire, 1895–2012.

Durham) no doubt contributed to record precipitation totals visible at the tail end of the 118-year time series (Figure 6).

Seasonal precipitation (Table 1) is increasing in spring, summer, and fall at all three sites, but decreasing during winter in Durham and Hanover (although only the summer trend in Durham is statistically significant). Decreases in winter precipitation at Durham and Hanover are primarily the result of decreasing snowfall between December and February (see *Snowfall* section on page 18).

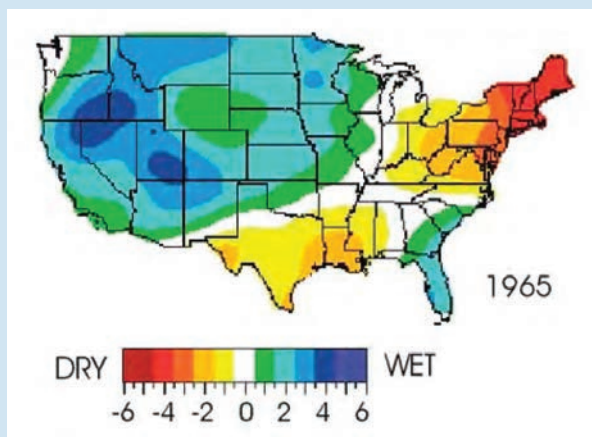
Extreme Precipitation Trends

While overall increases in precipitation have been modest, the frequency of the most extreme precipitation events (4 inches in 48 hours) has increased four to ten times since 1960, depending on the location of the station.

Climatologists have many metrics for defining a precipitation event as extreme. Using data from the USGCN-Daily stations, we quantify trends in three categories of extreme precipitation events: (1) greater than 1 inch in 24 hours, (2) greater than 4 inches in 48 hours, and (3) wettest day of the year.

Of the nine USGCN-Daily stations in southern New Hampshire that have sufficiently complete data to be included in our analysis (see Appendix A for details), seven show increasing trends in the number of events that produce more than 1 inch of precipitation (water equivalent) in 24 hours (Table 4); only Durham and Milford do not show a trend. The trends for the other seven stations range from an increase of +0.4 to +1.2 events per decade, equivalent to an increase of +2.1 to +6.4 events since 1960. These results are consistent with previous analyses.³⁵ Even greater changes are apparent when records of the largest precipitation events are examined—those that produce over 4

1960s DROUGHT ACROSS THE NORTHEAST UNITED STATES³⁴



The Palmer Drought Severity Index (PDSI) uses temperature and rainfall data to determine dryness. It is most effective in determining long term drought (several months to years). Zero is normal; minus 4 is extreme drought. Note the values below minus 4 for all of New England in 1965. Image from the NOAA National Climatic Data Center.

The drought of the 1960s was the most severe drought experienced by New Hampshire and New England over the past several hundred years. The drought had numerous negative impacts, including severe water shortages, degraded water quality, fish kills, increases in the number and severity of forest fires, and severely degraded pasture conditions. Extreme drought conditions affected over 60,000 square miles by the summer of 1965, when the drought reached its peak.

Precipitation shortfalls during spring and summer were the primary cause of the drought, but what caused the decrease in precipitation? Prevailing circulation patterns showed an unusually deep mid-tropospheric trough positioned just off the Atlantic Seaboard that pulled northerly cold, dry air masses over the Northeastern United States. The exact causes of the unusual jet stream pattern remain a mystery, but some scientists have concluded that colder than average sea surface temperatures along the continental shelf triggered the drought pattern of the 1960s.

inches of precipitation (water equivalent) in a 48-hour period, and which commonly result in flooding of our communities. Of the nine stations in southern New Hampshire, eight show an increase in the number of 4-inch precipitation events (Figure 7). Lakeport, Newport, Mt. Sunapee, Durham, Marlow, Keene, Milford, and Nashua show a four- to ten-fold increase in the number of these events per decade since the 1960s. Nashua experienced an astounding fourteen events from 2003 to 2012.

The amount of precipitation falling on the wettest day of the year is also rising (Table 4), with overall increases of about +0.1 inches per decade, equivalent to about half an inch more rain on the wettest day of the year over the past five decades.

Location	1 inch in 24 hrs		Wettest Day of the Year	
	1960-2012 mean (events/yr)	Trend (events/decade)	1960-2012 mean (inches)	Trend (inches/decade)
Hanover	7.6	0.4	2.21	0.08
Lakeport	9.0	<u>1.0</u>	2.48	0.14
Newport	8.3	<u>0.9</u>	2.39	0.09
Mt. Sunapee	11.3	<u>0.8</u>	2.74	<u>0.15</u>
Durham	10.5	0.0	3.08	0.06
Marlow	9.6	<u>0.8</u>	2.41	0.08
Keene	9.2	<u>1.2</u>	2.38	0.10
Milford	11.8	0.0	2.77	0.07
Nashua	11.8	<u>1.0</u>	2.66	<u>0.13</u>

TABLE 4. Extreme precipitation trends (greater than 1 inch in 24 hours) and wettest day of the year trends for USGCN-Daily stations located in southern New Hampshire for the period 1960–2012. Trends are estimated using Sen’s slope; statistically significant trends (p<0.05) are highlighted in **bold and underlined**.

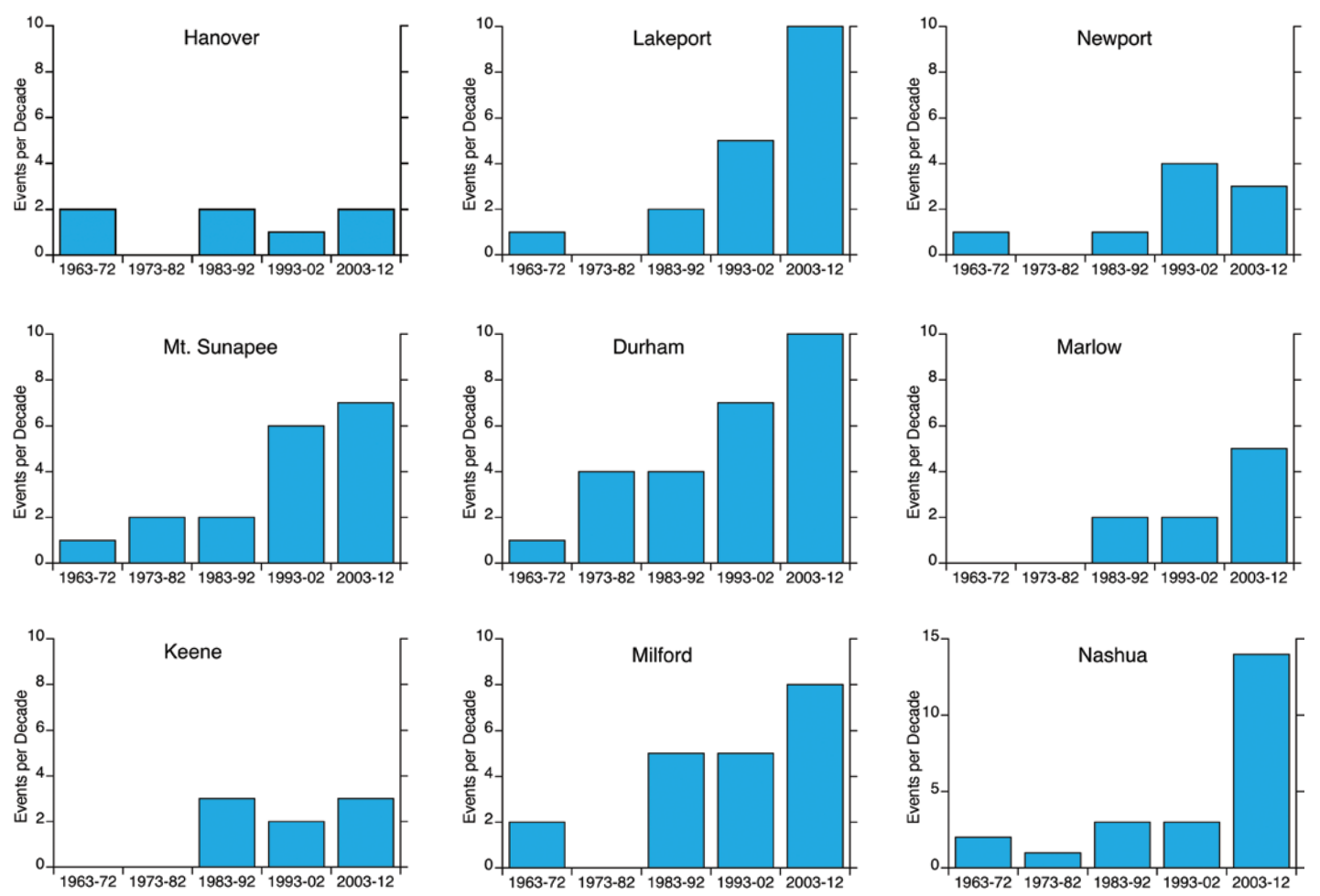


FIGURE 7. Trends in extreme precipitation events per decade (greater than 4 inches of precipitation in 48 hours) for nine GHCN-Daily stations in southern New Hampshire, 1963–2012.

Snowfall and Snow-Covered Day Trends

While snowfall shows no distinct trend across southern New Hampshire, the number of snow-covered days has decreased across most of the region over the past four decades.

If all else remains the same, warmer winters would be expected to reduce snowfall as more precipitation falls as rain versus snow. However, the response of snowfall trends to warmer winter temperatures is not as straightforward as might be expected. Warmer air masses hold more moisture; as long as temperatures remain below freezing, snowfall can be expected and may even increase in a slightly warmer climate. Only when temperatures rise above the freezing point can the region expect to see less snowfall in response to winter warming.

Observations show large spatial variability in snowfall trends throughout the northeastern United States.³⁶ Using data from the USGCN-Daily stations in southern New Hampshire, we calculate winter snowfall totals as the sum of all daily snowfall values for the months of December, January, February, and March (Table 5). Although traditionally designated as a spring month, we also include March in the winter analysis because snowfall and snow depth totals in March typically exceed those observed in December.

Overall, the mean snowfall trend for fourteen southern New Hampshire stations is a rather moderate decrease of -0.9 inches per decade. Six of the stations show decreasing trends in snowfall since 1970 (ranging from -1.4 to -9.1 inches per decade), two stations show no trend, and six stations show slight increasing trends (+0.2 to +2.6 inches per decade). Most of the reduction in snowfall is driven by decreases in December snowfall (eleven of the fourteen stations show a decreasing trend in December snowfall).

The number of snow-covered days in winter is closely tied to the amount of snowfall but also to

temperature trends through feedback processes related to the high reflectivity (albedo) of freshly fallen snow (think of how bright it is after a snowstorm). Following a fresh snowfall event, the overall reflectivity of the ground decreases as the overlying snow pack melts, ages, and retreats. The retreat exposes bare ground that has a significantly lower albedo. The decrease in reflectivity causes a surface to warm as it absorbs more and reflects less of the sun's energy.

In this analysis, we consider a day “snow-covered” if the daily snow depth value is greater than 1 inch. Monthly snow-covered days for December to March are summed to calculate the total number of snow-covered days in a given winter.

Overall, the mean number of snow-covered days in southern New Hampshire has been decreasing at a rate of two days per decade (Table 6). Of the eight USGCN-Daily stations that have reliable snow cover data, only Durham and Milford show statistically significant decreasing trends (-6.6 and -6.1 days per decade, respectively). Two other stations show decreasing trends, three stations show no trend, and one station (Newport) shows a weak increasing trend. The stations

Location	1970–2012 mean (inches)	Trend (inches/decade)
Hanover	56.3	-3.4
Lakeport	58.8	-1.2
Newport	60.4	0.2
Mt. Sunapee	68.6	0.2
Durham	41.8	-9.1
Marlow	67.0	2.6
Weare	64.0	0.0
Epping	54.5	-2.5
Greenland	53.6	2.8
Massebesic Lake	44.4	-2.1
Keene	51.1	0.3
Milford	54.7	-1.4
Nashua	49.3	0.0
Fitzwilliam	60.7	1.5

TABLE 5. Annual mean snowfall amount and decadal trends for USGCN-Daily stations located in southern New Hampshire for the period 1970–2012. Station list is sorted from north (top of the table) to south (bottom of the table). Trends are estimated using Sen's slope; statistically significant trends ($p < 0.05$) are highlighted in **bold and underlined**.

with decreasing trends are consistent with broader scale declines in North American mid-latitude snow cover extent quantified from analysis of satellite records.³⁷

Lake Ice-Out Trends:
Lake Winnepesaukee and Lake Sunapee

Spring ice-out dates have been getting earlier over the past 115 years. Since 1970, ice-out dates on Lakes Winnepesaukee and Sunapee are occurring about a week earlier.

Lake ice-out dates are frequently used as an indicator of winter/early spring climate change due to the close correlation with surface air temperature in the months before ice break-up.³⁸ Changes in the timing of lake ice-out can increase phytoplankton productivity³⁹ and subsequently deplete summer oxygen levels⁴⁰ as the phytoplankton blooms are decayed through bacterial respiration. Earlier ice-out dates also impact the ice fishing and snowmobiling industry by shortening the winter recreation season or, worse, eliminating it altogether during years when lakes do not ice over completely.

Records of lake ice-out have been kept on Lake Winnepesaukee since 1887, and on Lake Sunapee since 1869. For Lake Winnepesaukee, the criteria used to determine the official date of lake ice-out has varied over the years, but the vast majority of the record has been declared when the 230-foot long M/S Mount Washington can safely navigate between her port stops of Alton Bay, Center Harbor, Weirs Beach, Meredith, and Wolfeboro. The criteria for the official declaration of lake ice-out on Lake Sunapee have similarly varied throughout the years.

In 2010 and again in 2012, the earliest ice-out day (Julian day 83—March 24th in 2010 and March 23rd

Location	1970–2012 mean (days)	Trend (days/decade)
Hanover	85	-2.9
Newport	84	0.6
Durham	58	<u>-6.6</u>
Marlow	92	0.0
Weare	79	-0.8
Greenland	59	0.0
Keene	75	0.0
Milford	81	<u>-6.1</u>

TABLE 6. Annual mean snow-covered days and decadal trends for USGCN-Daily stations located in southern New Hampshire for the period 1970–2012. Station list is sorted from north (top of the table) to south (bottom of the table). Trends are estimated using Sen’s slope; statistically significant trends (p<0.05) are highlighted in **bold and underlined**.

in 2012 because of the leap year) was recorded on Lake Winnepesaukee, breaking the previous record set on March 28th, 1921 (Julian day 87) by four days (Figure 8a). The latest ice-out ever declared on Lake Winnepesaukee occurred on May 12th, 1888 (Julian day 133). Overall, the ice-out dates have been getting earlier over the past 115 years. Since 1970, ice-out dates are occurring on average about a week earlier in the year.

The earliest ice-out date at Lake Sunapee also occurred in 2012 on March 23rd (Julian day 82). There has also been a clear trend to earlier ice-out dates over the past four decades. The recent trends of earlier ice-out dates for Lake Winnepesaukee and Lake Sunapee are consistent with twenty-eight other long-term ice-out records from New Hampshire, Maine, and Massachusetts.⁴¹ In addition, the ice extent on the Great Lakes has decreased substantially since 1973 due to warmer winters⁴²; less ice corresponds with more open water, which can result in heavier lake-effect snow in regions downwind of the Great Lakes.

Impacts of Weather Disruption

One measure of the impact of weather disruption on New Hampshire is the money that the Federal Emergency Management Administration (FEMA) has spent on Presidentially Declared Disasters and Emergency Declaration (Figure 9).⁴³ From the period 1986 to 2004, there was only one event (the 1998 ice storm) where damages paid out by FEMA were greater than \$10 million (in 2012 dollars). Conversely, five of the seven years between 2005 and 2012 had weather events where damages paid out by FEMA were greater than \$10 million (in 2012 dollars). The most significant damages between 2005 and 2012 resulted from floods and ice storms. The shift in 2005 is not only due to an increase in extreme weather events, but also reflects the fact that our infrastructure (buildings, roads, electrical grid) has been developed in ways that make them vulnerable to damage from these extreme events.

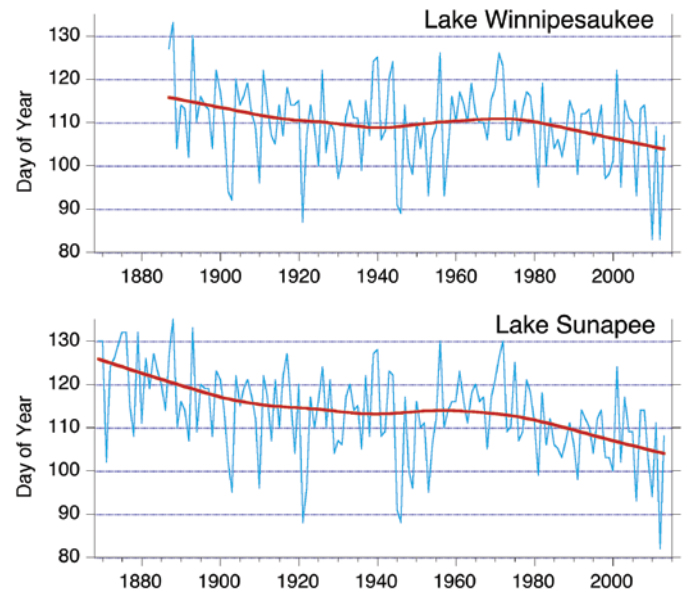


FIGURE 8. Annual ice-out dates (blue) in Julian days (number of days past January 1st) for Lake Winnepesaukee (1887–2013; top) and Lake Sunapee (1869–2013; bottom). Red line represents weighted curve fit uses the locally weighted least squares error (Lowess) method.

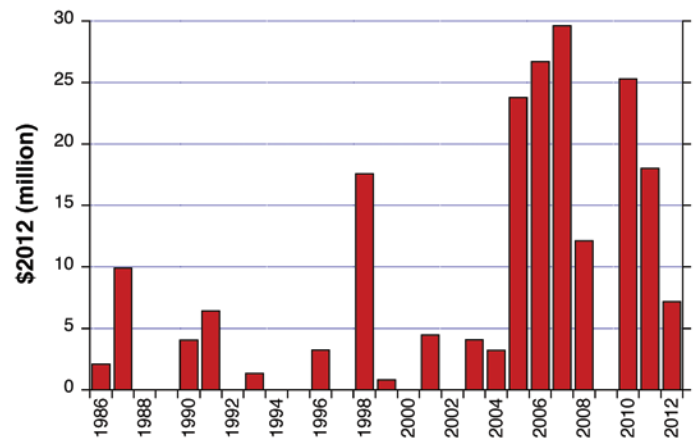


FIGURE 9. Federal expenditures on Presidentially Declared Disasters and Emergency Declarations in New Hampshire from 1999 to 2012. Expenditures adjusted to \$2012 using the consumer price index. Note increase in expenditures since 2005.

III. FUTURE CLIMATE CHANGE

“Human-induced climate change is projected to continue and accelerate significantly if emissions of heat-trapping gases continue to increase. Heat-trapping gases already in the atmosphere have committed us to a hotter future with more climate-related impacts over the next few decades. The magnitude of climate change beyond the next few decades depends primarily on the amount of heat-trapping gases emitted globally, now and in the future.”⁴⁴

Projections of future climate were developed using four global climate models (GCMs)—complex, three-dimensional coupled models that incorporate the latest scientific understanding of the atmosphere, oceans, and Earth’s surface—using two different scenarios of future global emissions of heat-trapping gases as input. The GCM simulations were then statistically downscaled using the Asynchronous Regional Regression Model.⁴⁵ Here, downscaling was conducted using the entire record from 1960 to 2012 to include as broad a range of observed variability as possible. Downscaling was conducted and tested using observed daily minimum and maximum temperature for twenty-five GHCN-Daily stations in southern New Hampshire (south of latitude 43.9 N; Figure 10, Table 7) and observed 24-hour cumulative precipitation for forty-one GHCN-Daily stations in southern New Hampshire (Figure 11, Table 8). Details of the methods used to develop projections of future climate, including global emission scenarios, GCMs, statistical downscaling model, and a discussion of uncertainty, are provided in Appendix A.

Station Name	Latitude (N)	Longitude	Elevation (ft)	StationID
Tamworth	43.90	-71.30	241	278612
Plymouth	43.78	-71.65	201	276945
Hanover	43.71	-72.29	178	273850
Grafton	43.57	-71.95	253	273530
Lakeport	43.55	-71.47	171	274475
Lakeport2	43.55	-71.46	152	274480
Franklin Falls	43.47	-71.67	131	273182
Franklin	43.45	-71.67	119	273177
Newport	43.38	-72.18	235	275868
Mt. Sunapee	43.33	-72.08	387	275629
Blackwater Dam	43.32	-71.72	183	270741
Durham	43.14	-70.95	23	272174
Deering	43.09	-71.87	325	271950
East Deering	43.07	-71.82	241	272284
Manchester	43.03	-71.48	64	275072
Epping	43.03	-71.08	49	272800
Greenland	43.02	-70.83	26	273626
Surry Mtn	43.00	-72.31	171	278539
Massabesic Lake	42.99	-71.39	77	275211
Keene	42.94	-72.32	156	274399
Peterboro	42.85	-71.95	311	276697
Windham	42.82	-71.33	67	279740
Nashua	42.79	-71.47	41	275712
Hudson	42.78	-71.41	56	274234
Nashua2	42.77	-71.45	27	275702

TABLE 7. Location of 25 GHCN-Daily stations in southern New Hampshire with minimum and maximum temperature data for the period 1960–2009 that were used to downscale Global Climate Model simulations. Station list is sorted from north (top of the table) to south (bottom of the table).

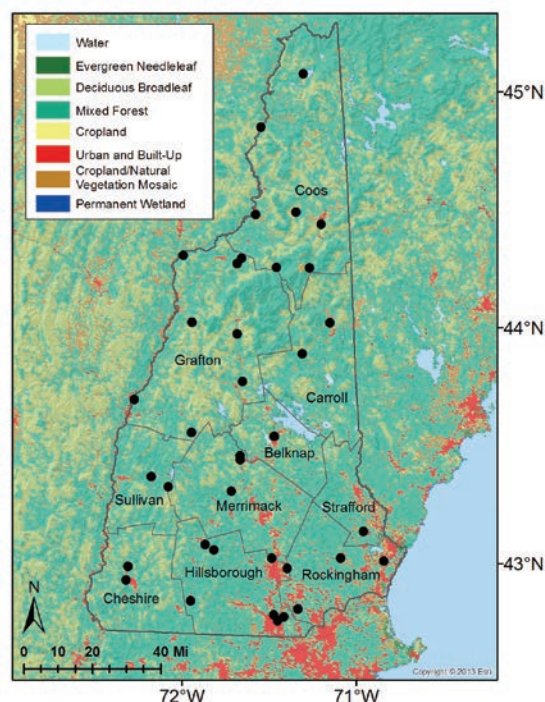


FIGURE 10. Location map for Global Historical Climatology Network (GHCN)-Daily stations (black dots) in New Hampshire with daily minimum and maximum temperature records for the period 1960–2012. Data used to investigate climate change in southern New Hampshire comes from the 25 stations below 43.9°N latitude.

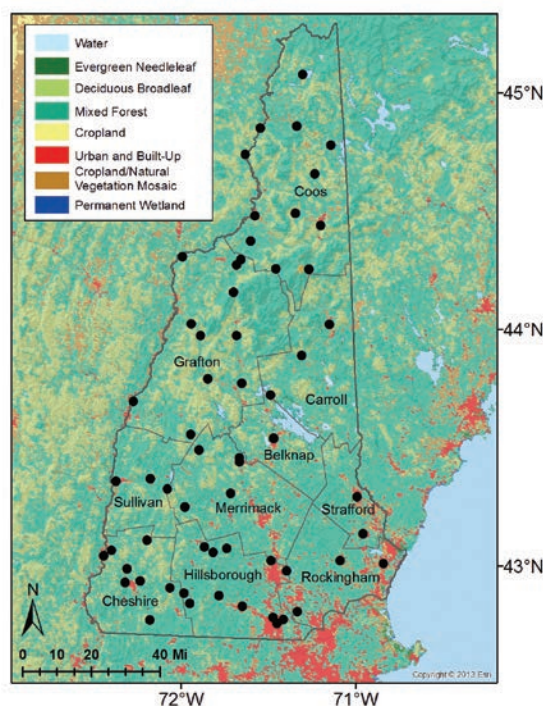


FIGURE 11. Location map for Global Historical Climatology Network (GHCN)-Daily stations (black dots) in New Hampshire with daily precipitation records for the period 1960–2012. Data used investigate climate change in southern New Hampshire comes from the 41 stations below 43.9°N latitude.

Station Name	Latitude (N)	Longitude	Elevation (ft)	StationID
Tamworth	43.90	-71.30	241	278612
West Rumney	43.80	-71.85	171	279474
Plymouth	43.78	-71.65	201	276945
Moultonboro	43.73	-71.48	183	275532
Hanover	43.71	-72.29	178	273850
Grafton	43.57	-71.95	253	273530
Lakeport	43.55	-71.47	171	274475
Lakeport2	43.55	-71.46	152	274480
South Danbury	43.50	-71.90	284	277967
Franklin Falls Dam	43.47	-71.67	131	273182
Franklin	43.45	-71.67	119	273177
Newport	43.38	-72.18	235	275868
Claremont Junction	43.37	-72.38	131	271552
Mt. Sunapee	43.33	-72.08	387	275629
Blackwater Dam	43.32	-71.72	183	270741
Rochester	43.30	-70.98	70	277253
Bradford	43.26	-71.98	287	270910
Durham	43.14	-70.95	23	272174
Marlow	43.12	-72.20	360	275150
Deering	43.09	-71.87	325	271950
Weare	43.08	-71.74	220	278972
East Deering	43.07	-71.82	241	272284
Walpole	43.07	-72.41	284	278858
Walpole2	43.05	-72.45	92	278855
Epping	43.03	-71.08	49	272800
Manchester	43.03	-71.48	64	275072
Greenland	43.02	-70.83	26	273626
Surry Mtn. Lake	43.00	-72.31	171	278539
Massabesic Lake	42.99	-71.39	77	275211
Otter Brook lake	42.95	-72.24	207	276550
Keene	42.94	-72.32	156	274399
Dublin	42.92	-72.07	454	272136
Edward Macdowell Lake	42.89	-71.98	296	275013
South Lyndeboro	42.88	-71.78	198	278081
Peterboro	42.85	-71.95	311	276697
Milford	42.84	-71.65	98	275412
Windham	42.82	-71.33	67	279740
Nashua	42.79	-71.47	41	275712
Fitzwilliam	42.78	-72.18	363	273024
Hudson	42.78	-71.41	56	274234
Nashua	42.77	-71.45	27	275702

TABLE 8. Location of 41 GHCN-Daily stations in southern New Hampshire with precipitation data for the period 1960–2009 that were used to downscale Global Climate Model simulations. Station list is sorted from north (top of the table) to south (bottom of the table).

Future Annual and Seasonal Temperature

Average annual temperatures are projected to increase by about 2°F in the short-term (2010–2039). Over the long-term (2070–2099), the amount of projected warming under the higher emissions scenario (+8 to +9°F) is twice that compared to the lower emissions scenario (+4°F).

Temperatures in southern New Hampshire will continue to rise regardless of whether the future follows a lower or higher emissions scenario. This is due to two reasons: first, because some amount of change is already entailed by past emissions; and second, because it is impossible to stop all emissions of heat-trapping gases today and still supply society's energy needs. For both of those reasons, the warming expected over the next few decades is nearly identical under a higher or a lower scenario. However, it is clear that the magnitude of warming that can be expected after the middle of this century will depend on which emissions pathway is followed during the first-half of the century (Figure 12 and 13; Table 9).

During the first part of the twenty-first century (2010–2039), annual temperature increases are similar for the lower (B1) and higher (A1fi) emissions scenarios for maximum and minimum temperatures. The warming by 2040 (Figures 12 and 13) therefore represents an amount of warming that we have already baked into the climate system (regardless of the emissions scenario followed) and an amount of warming we need to begin preparing for and adapting to.

The magnitude of warming begins to diverge during the middle part of the century (2040–2069), with the higher emissions scenario resulting in greater rates and overall amounts of warming compared to the lower emissions scenario. Temperature increases under the higher emissions scenario are nearly twice that expected under the lower emissions scenario by the

CLIMATE GRIDS AND MAPS OF FUTURE CLIMATE CHANGE

Chapter III of this report discusses many of the projected changes in climate under a higher and a lower future emissions scenario. Additional detailed information is provided in the climate grids (Appendix B), which contain historical and projected future 30-year climatologies for twenty-five Global Historical Climatology Network-Daily (GHCN-Daily) meteorological stations in southern New Hampshire (that is, south of 43.9° north latitude) for the historical period (1980–2009) and the future (near-term [2010–2039], medium-term [2040–2069], and long-term [2070–2099]). The projected values represent the statistically downscaled average of daily simulations from four GCMs. Temporal averages were first calculated for each individual GCM, and then the results of all four GCMs were averaged. The climate grids include thirty-year averages of daily measures for minimum and maximum temperature (annual, seasonal, extremes), length of the growing season, precipitation (annual, seasonal, extremes), and snow-covered days.

In addition, maps (similar to those shown in Figures 15 and 19) for the state of New Hampshire for all twenty-five climate indicators listed in Table 9 for the historical time period and for three thirty-year time periods in the future can be viewed online at the New Hampshire Experimental Program to Stimulate Competitive Research (EPSCoR) — Data Discovery Center.⁴⁶

end of the twenty-first century (2070–2099). Overall, southern New Hampshire can expect to see increases in annual maximum and minimum temperature ranging from +4°F to +9°F by 2070–2099.

Historically, average winter temperatures showed the greatest warming over the past four decades,⁴⁷ but that isn't necessarily the case for future scenarios. While annual and seasonal maximum temperatures all increase, the largest increase occurs in the spring

and summer seasons for both the lower (+6.6°F and +4.1°F, respectively) and higher (+8.7°F and +9.6°F, respectively) emissions scenarios by end of century. For minimum temperatures, the higher emissions scenario shows warming in all seasons (ranging from +8.3 - +9.3°F), while the lower emission scenarios shows the greatest amount of warming in the spring (+6.8°F) and winter (+5.0°F) by end of century.

With regard to climate impacts, the projected

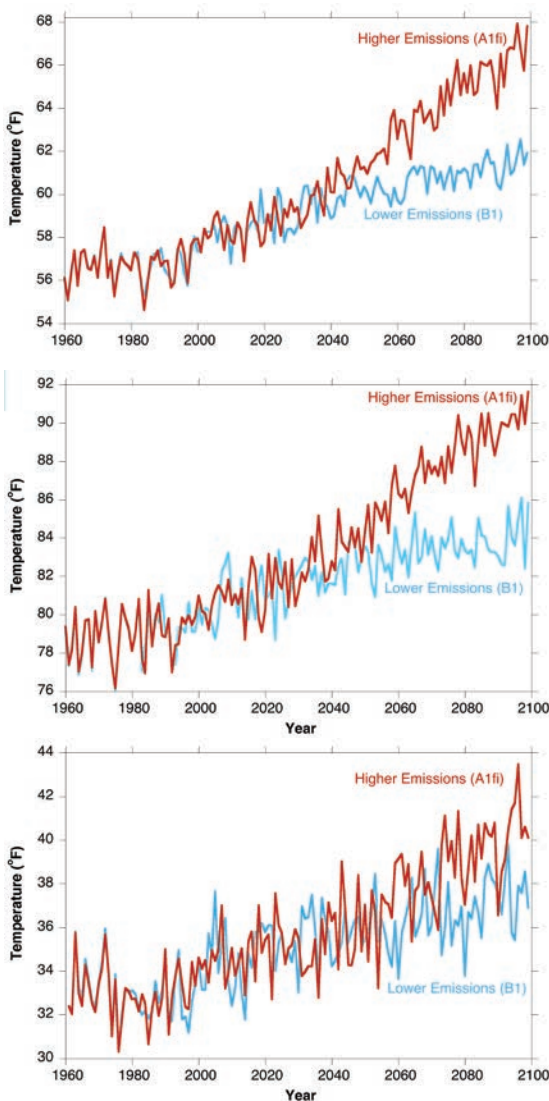


FIGURE 12. Modeled *maximum* temperatures for southern New Hampshire (averaged over 25 sites) from the higher emission scenario (A1fi; red line) and lower mission scenario (B1; blue line) for a) annual (top), b) summer (middle), and c) winter (bottom), 1960–2099.

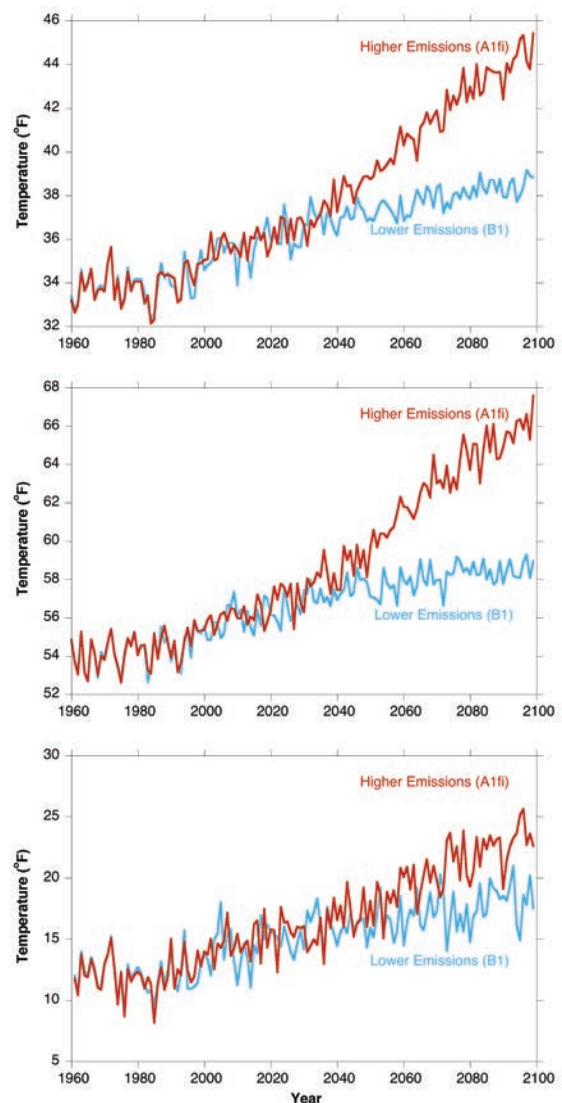


FIGURE 13. Modeled *minimum* temperatures for southern New Hampshire (averaged over 25 sites) from the higher emission scenario (A1fi; red line) and lower mission scenario (B1; blue line) for a) annual (top), b) summer (middle), and c) winter (bottom), 1960–2099.

increases in southern New Hampshire winter maximum and minimum temperature will very likely push regional average winter temperatures above the freezing point. With average winter temperatures above freezing, the region can expect to see a greater proportion of winter precipitation falling as rain (as opposed to snow), earlier lake ice-out dates, and a decrease in the number of days with snow cover. Warmer summer temperatures will likely lead to an increase in drought (through increased evaporation, heat waves, and more frequent and extreme convective precipitation events).

Future Extreme Temperature

As temperatures increase in southern New Hampshire, the number of very hot days is expected to become more frequent and the hottest days hotter, while extreme cold is expected to become less frequent and the coldest days less severe.

Extreme Heat

Increases in extreme heat are calculated using three metrics: (1) number of days above 90°F, (2) number of days above 95°F, and (3) average temperature on the hottest day of the year (Table 9). During the historical baseline period from 1970–1999, southern New Hampshire experienced, on average, seven days per year above 90°F each year, with more hot days at sites in the far southern regions of New Hampshire (for example, Manchester; Figure 14). By 2070–2099, southern New Hampshire on average can expect twenty-three days per year with daytime maximum temperatures above 90°F under the lower emissions scenario and over fifty-four days per year under the higher emissions scenario, about eight times the historical average (Figure 14). Under the higher emissions scenario, Manchester would experience over seventy days per summer with temperatures above 90°F, essentially making the summer a prolonged heat wave punctuated by slightly less uncomfortable days.

IMPACTS OF FUTURE CLIMATE CHANGE ON SOUTHERN NEW HAMPSHIRE

This report provides a detailed assessment of how climate will change across southern New Hampshire depending on the levels of future emissions of heat-trapping gases from human activities. The next step is to examine how climate change will impact the region's environment, ecosystem services, economy, and society. A detailed analysis of the impacts of climate change in southern New Hampshire is beyond the scope of this report. Fortunately, there is a wealth of analysis on the potential impacts of climate change across New England and the northeast United States provided in the reports and peer-reviewed scientific papers written as part of the Northeast Climate Impacts Assessment (NECIA).⁴⁸ The NECIA Executive Summary, Full Report, and state-based analysis are all available on the NECIA website.⁴⁹

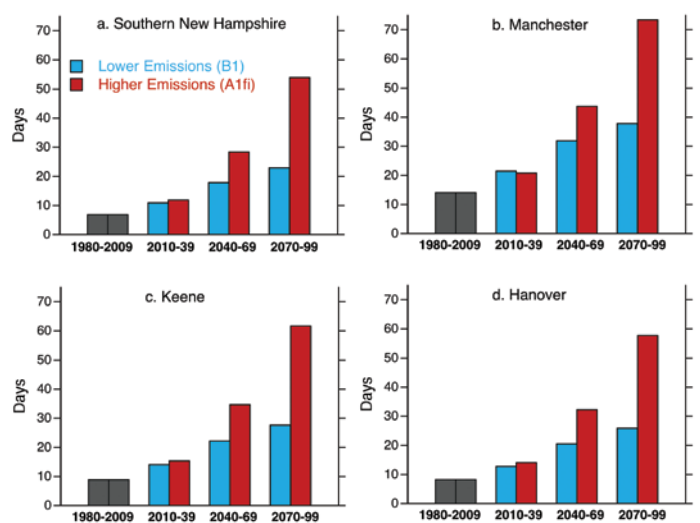


FIGURE 14. Historical (grey) and projected lower emissions (blue) and higher emissions (red) average number of days above 90°F per year, shown as 30-year averages for a) southern New Hampshire (average of 25 stations), b) Manchester, c) Keene, and d) Hanover.

Under the lower emissions scenario, Manchester would experience forty days per summer with temperatures above 90°F.

Between 1980–2009, extreme daytime maximum temperatures above 95°F were historically rare, occurring on average one day per year across southern New Hampshire. Under the lower emissions scenario, southern New Hampshire can expect to experience six days per year above 95°F (Table 9). Under the higher emissions scenario, the number of days above 95°F is expected to increase to twenty-two days per year by end of century.

As the number of extremely hot days per year increases, the average daytime maximum temperature on the hottest day of the year is also expected to increase (Figure 15). By the 2070–2099 period, the temperature on the hottest day of the year could climb to 98°F under the lower emissions scenario and upwards of 102°F under the higher emissions scenario compared to the historical average of 93°F.

Extreme Cold

Increases in extreme cold are calculated using three metrics: (1) number of days below 32°F, (2) number of days below 0°F, and (3) average nighttime minimum temperature on the coldest day of the year. Over the period 1980–2009, southern New Hampshire experienced on average 164 days per year with nighttime minimum temperatures below 32°F (Table 9), roughly the length of the winter season from mid-November through mid-April. Over the next century, these numbers are expected to decrease considerably. By the end of the century, southern New Hampshire could experience forty-four fewer days per year with minimum temperatures below 32°F under the higher emissions scenario, or about a 25 percent decline.

Under the lower emissions scenario, twenty fewer days per year are expected, or about a 12 percent decline by end of century.

Decreases in the number of extreme cold days below 0°F are more noticeable compared to days below 32°F. Southern New Hampshire currently



FIGURE 15. Historical (left) and projected (2070–2099) lower emissions (center) and higher emissions (right) average daytime maximum temperature on the hottest day of the year across New Hampshire.

experiences on average sixteen days per year when minimum temperatures fall below 0°F (Table 9). That number will be halved by 2040–2060 to about eight days per year under the lower emissions scenario, and only five to six days under the higher emissions scenario. By the end of the twenty-first century, results indicate a decrease of 88 percent under the higher emissions scenario and a decrease of 56 percent under the lower emissions scenario in the number of days with minimum temperatures less than 0°F.

The average nighttime minimum temperature on the coldest day of the year in southern New Hampshire currently averages -15°F. This is projected to gradually warm over this century. By the end of the century, the minimum temperature per year is expected to warm +8°F under lower emissions and +17°F under higher emissions (Table 9).

Future Growing Season

By the end of the century, the growing season is projected to lengthen by about two weeks under the lower emission scenario or five weeks under the higher emission scenario. However, hotter temperatures, reduced chilling hours, enhanced evapotranspiration, and more extreme precipitation will likely result in a decrease in crop yields.

A longer growing season may provide opportunities for farmers to grow new crops that require a longer (frost-free) growing season. However, analysis of the impact of future climate on agricultural production indicates that many crops will have yield losses associated with increased frequency of high temperature stress, inadequate winter chill period for optimum fruiting, and increased pressure from invasive weeds, insects, or disease that are currently not a significant factor in New Hampshire.⁵⁰ Furthermore, several weeds are likely to benefit more than crops from higher temperatures and increasing concentrations of atmospheric carbon

dioxide.⁵¹ Another concern involves the northward spread of invasive weeds like privet and kudzu, which are already present in the South.⁵² More hot days also indicate a substantial potential negative impact on milk production from dairy cows, as milk production decreases with an increase in the thermal heat index.⁵³ Higher CO₂ levels result in stronger growth and more toxicity in poison ivy,⁵⁴ while higher temperatures combined with higher CO₂ levels also lead to substantial increases in aeroallergens that have significant implication for human health.⁵⁵

The length of the growing season will continue to increase under both emission scenarios (Figure 16). In the short term (2010–2039), the average growing season is likely to be extended by eleven to twelve days across southern New Hampshire, an increase of about 7 percent. By the end of the century, the growing season is projected to increase by twenty days under the lower emission scenarios (12 percent increase) to forty-nine days under the higher emissions scenario (30 percent).

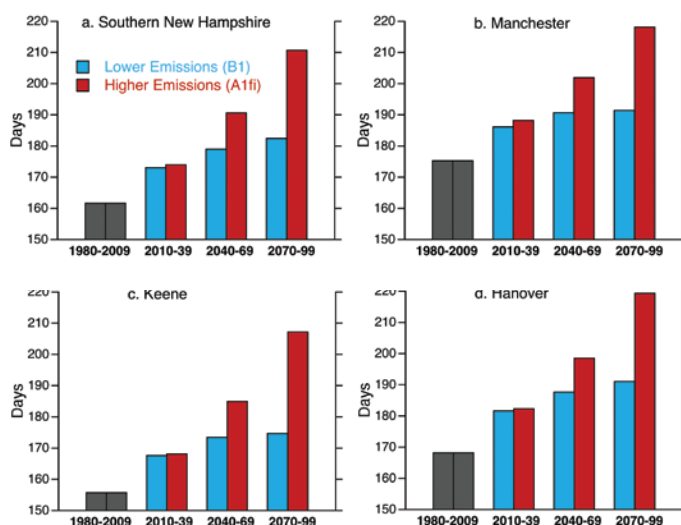


FIGURE 16. Historical (grey) and projected lower emissions (blue) and higher emissions (red) average length of the growing season (using a threshold of 28°F), shown as 30-year averages for a) southern New Hampshire (average of 25 stations), b) Manchester, c) Keene, and d) Hanover.

Southern New Hampshire

Indicators	Historical* 1980–2009	Change from historical (+ or -)					
		Short Term 2010–2039		Medium Term 2040–2069		Long Term 2070–2099	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions
Minimum Temperature (°F)							
Annual TMIN	34.5	1.7	2.0	2.9	5.1	3.8	8.8
Winter TMIN	12.8	2.3	2.6	3.6	5.6	5.0	9.3
Spring TMIN	31.2	4.0	2.5	5.6	5.2	6.8	8.5
Summer TMIN	54.9	1.6	2.2	2.8	5.6	3.5	9.8
Fall TMIN	35.3	0.3	1.7	0.6	5.0	1.1	8.3
Maximum Temperature (°F)							
Annual TMAX	57.2	1.7	1.7	3.0	4.8	4.1	8.3
Winter TMAX	33.4	1.7	1.6	2.5	3.5	3.6	6.1
Spring TMAX	55.7	2.5	1.5	4.9	4.7	6.6	8.7
Summer TMAX	79.6	1.8	2.1	3.3	5.7	4.1	9.6
Fall TMAX	59.7	0.9	1.7	1.3	5.3	1.5	8.6
Temperature Extreme (days per year)							
<32°F	164.0	-9.5	-10.9	-15.8	-25.5	-19.5	-43.9
<0°F	16.0	-5.0	-5.1	-7.8	-10.6	-9.0	-14.2
>90°F	6.7	4.2	5.2	11.1	21.7	16.2	47.3
>95°F	1.0	0.8	1.2	2.7	7.0	5.1	21.8
TMAX on hottest day of year	93.1	1.8	1.4	3.0	4.8	4.6	9.0
TMIN on coldest day of year	-15.8	4.0	4.4	6.2	10.2	8.0	17.4
Growing Season (days)	162	11.1	12.0	17.0	28.6	20.4	48.7
Precipitation (inches)							
Annual mean	43.8	4.3	3.1	5.4	5.9	7.4	8.8
Winter mean	9.8	1.2	0.9	1.5	1.5	2.1	2.9
Spring mean	10.9	1.1	1.1	1.7	1.6	2.1	2.7
Summer mean	11.4	1.7	1.0	1.3	2.0	2.2	1.6
Fall mean	11.6	0.5	0.2	1.0	0.9	1.1	1.6
Extreme Precipitation (events per year)							
1" in 24 hrs	10.4	1.6	1.6	2.2	2.8	2.9	4.3
2" in 48 hours	3.7	2.0	2.0	1.0	3.0	1.5	4.2
Extreme Precipitation (events per decade)							
4" in 48 hours	4.3	2.6	0.7	3.9	4.0	6.1	7.6
Snow Covered Days	105	-9.6	-16.3	-15.0	-37.1	-23.7	-52.9

TABLE 9. Climate grid with historical and projected future 30-year climatologies for temperature (25 stations) and precipitation (41 stations) variables averaged across southern New Hampshire (south of 43.9° north latitude). Daily meteorological data was not available for all sites for the entire period of record, so the historical values (1980–2009) in these tables were derived from the downscaled GCM simulations. A climate grid for each of the 25 GHCN-Daily stations that recorded both temperature and precipitation are provided in Appendix B.

Future Precipitation

The amount of annual precipitation is projected to continue to increase over this century.

Future trends in annual and seasonal precipitation point toward wetter conditions in southern New Hampshire over the coming century, continuing the historical trend observed over the past four decades. Annual precipitation is projected to increase 17 to 20 percent under both emission scenarios by the end of the century, slightly more under the high emissions scenario compared to the low emissions scenario by the end of the century (Figure 17; Table 9). Under both emission scenarios, precipitation increases are largest during winter and spring and increase only slightly during the summer and fall.

Future Extreme Precipitation and Drought

The frequency of extreme precipitation events is projected to more than double by the end of the century under both lower and higher emission scenarios.

There are potential benefits that may result from an increase in total annual precipitation—alleviation of scarce water resources, less reliance on irrigation, and increased resilience to drought. In a world where freshwater resources will likely be stressed by the combination of precipitation reductions and warmer temperatures in some regions (for example, the southwestern United States⁵⁶) and increasing demand, increases in annual precipitation could be extremely valuable in many respects for New Hampshire and New England. However, those benefits may not occur if the increase in precipitation is primarily the result of an increase in extreme precipitation events, which can lead to excessive runoff, flooding, damage to

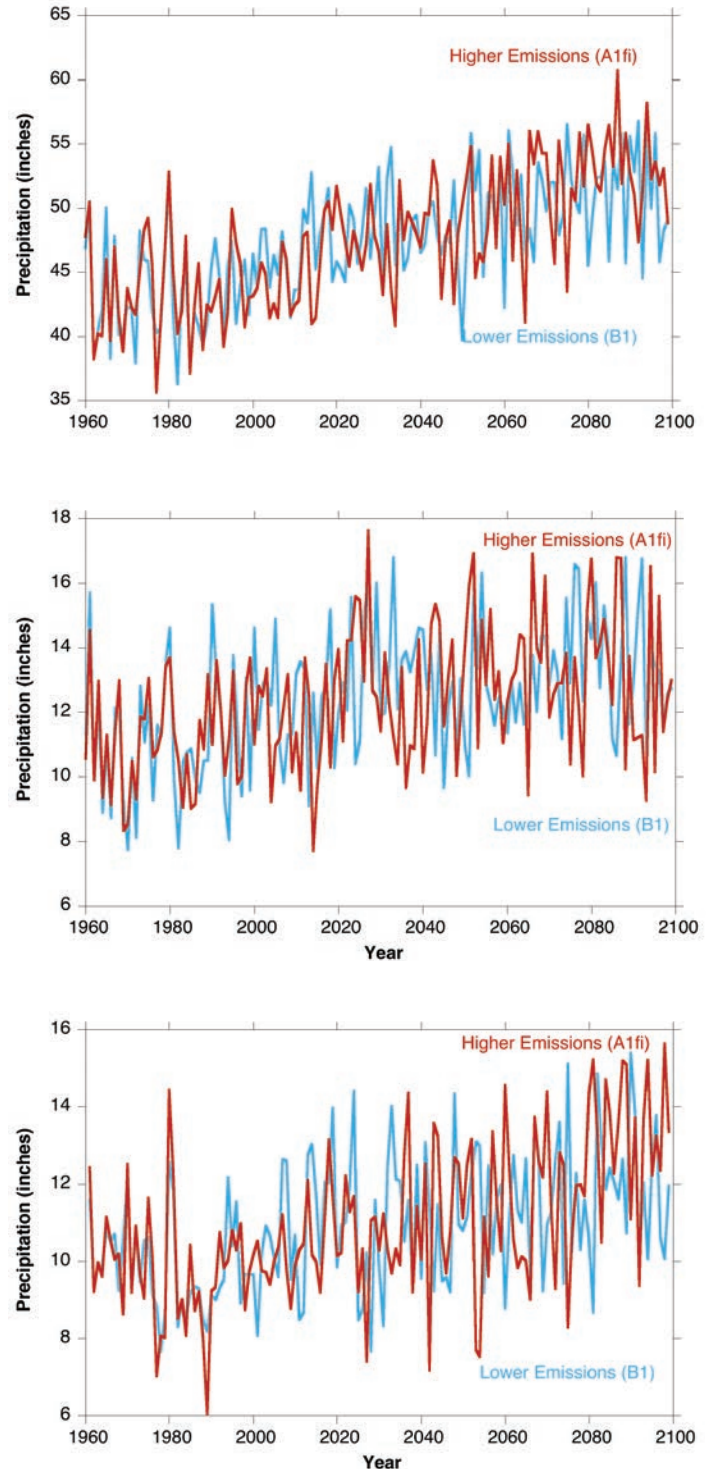


FIGURE 17. Historical and projected a) annual (top), b) summer (middle), and c) winter (bottom) precipitation for southern New Hampshire (averaged over 41 sites) from the higher emission scenario (A1fi; red line) and lower mission scenario (B1; blue line), 1960–2099.

critical infrastructure (including buildings, roads, dams, bridges, and culverts), increased erosion, and degradation of water quality.

The same three metrics described in the historical analysis are presented for higher and lower future emissions scenarios: (1) greater than 1 inch in 24 hours, (2) greater than 4 inches in 48 hours, and (3) wettest day of the year (Table 9). For all three metrics, it is clear that southern New Hampshire can expect to see more extreme precipitation events in the future, and more extreme precipitation events under the higher emissions scenario relative to the lower emissions scenario.

Historically, southern New Hampshire experienced 10.4 events per year with greater than 1 inch of precipitation in 24 hours. By 2070–2099, that will increase to 13.3 events under the lower emissions scenario and to 14.7 events for the higher emissions scenario in the medium- and long-term. For events with greater than 2 inches in 48 hours, southern New Hampshire averaged 3.7 events per year from 1980–2009, but that will increase to 5.2 events per year under the lower emissions scenario and will more

than double to 7.9 events per year under the higher emissions scenario. However, the largest changes are projected to occur for the more extreme precipitation events, here defined as greater than 4 inches in 48 hours. These are also the events that have seen the strongest historical increases. These events are expected to increase from the current 4.3 events per decade (again, averaged across southern New Hampshire; see Figure 7 for an example of the large spatial variability of these events across the region) to more than ten events per decade under the lower emissions scenario, and almost twelve events per decade under the higher emissions scenario (Figures 18 and 19).

No new analysis of future drought was performed for this report. However, hydrologic simulations from the Variable Infiltration Capacity (VIC) model are available, which use the same GCM inputs as the analysis presented in this report.⁵⁷ VIC is a hydrological model that simulates the full water and energy balance at the Earth’s surface and provides a daily measure of soil moisture resulting from a broad range of hydrological processes, including precipitation and evaporation. Based on VIC simulations of soil moisture, a drought event was defined as the number of consecutive months with soil moisture percentile values less than 10 percent, with droughts being classified as short- (one to three months), medium- (three to six months), and long-term (six plus months). The results⁵⁸ indicate that over the long-term (2070–2099) under the higher emissions scenario, New Hampshire, New England, and upstate New York can expect to experience a two- to three-fold increase in the frequency of short-term drought and more significant increases in medium-term drought. These droughts are driven primarily by an increase in evapotranspiration resulting from hotter summers. Note that summer precipitation shows only a slight increase (Table 9), not enough to offset the increase in

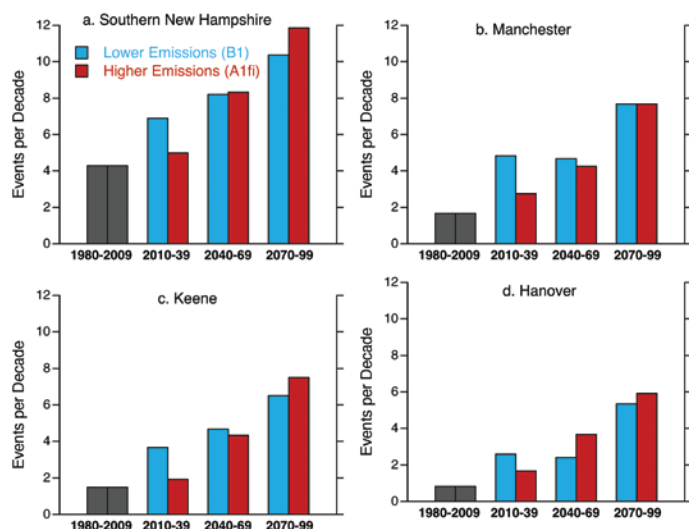


FIGURE 18. Historical (grey) and projected lower emissions (blue) and higher emissions (red) average number of precipitation events per decade with more than 4 inches of rain in 48 hours, shown as 30-year averages for a) southern New Hampshire (average of 41 stations), b) Manchester, c) Keene, and d) Hanover.

evapotranspiration resulting from hotter temperatures. Under the lower emissions scenario, the frequency of short- and medium-term drought increases only slightly by the end of the century. The frequency of long-term drought does not change substantially across New Hampshire in the future under either emissions scenario compared to the frequency of long-term drought in the past.

The projections of hotter summers and more frequent short- and medium-term droughts suggest potentially serious impacts on water supply and agriculture. Even very short water deficits (on the order of one to four weeks) during critical growth stages can have profound effects on plant productivity and reproductive success. During a drought, evapotranspiration continues to draw on surface water resources, further depleting supply. As a water deficit deepens, productivity of natural vegetation and agriculture drops. The projected drought also poses a risk to the summertime drinking water supply across the region.

Future Snow Cover

By the end of the century, snow-covered days are projected to decrease by 20 percent under the lower emissions scenario or 50 percent under the higher emissions scenario.

Changes in future snow cover will depend on both temperature and precipitation. As shown earlier, the projected increases in winter maximum and minimum temperature in southern New Hampshire will very likely push the regional average winter temperatures above the freezing point by the end of the twenty-first century. This suggests that a greater proportion of winter precipitation will fall as rain as opposed to snow. At the same time, precipitation is expected to increase in winter and spring, potentially increasing total snowfall in the near term as long as below-freezing temperatures continue to occur on days when precipitation is falling. Projected changes in the number of winter days with snow cover (greater than

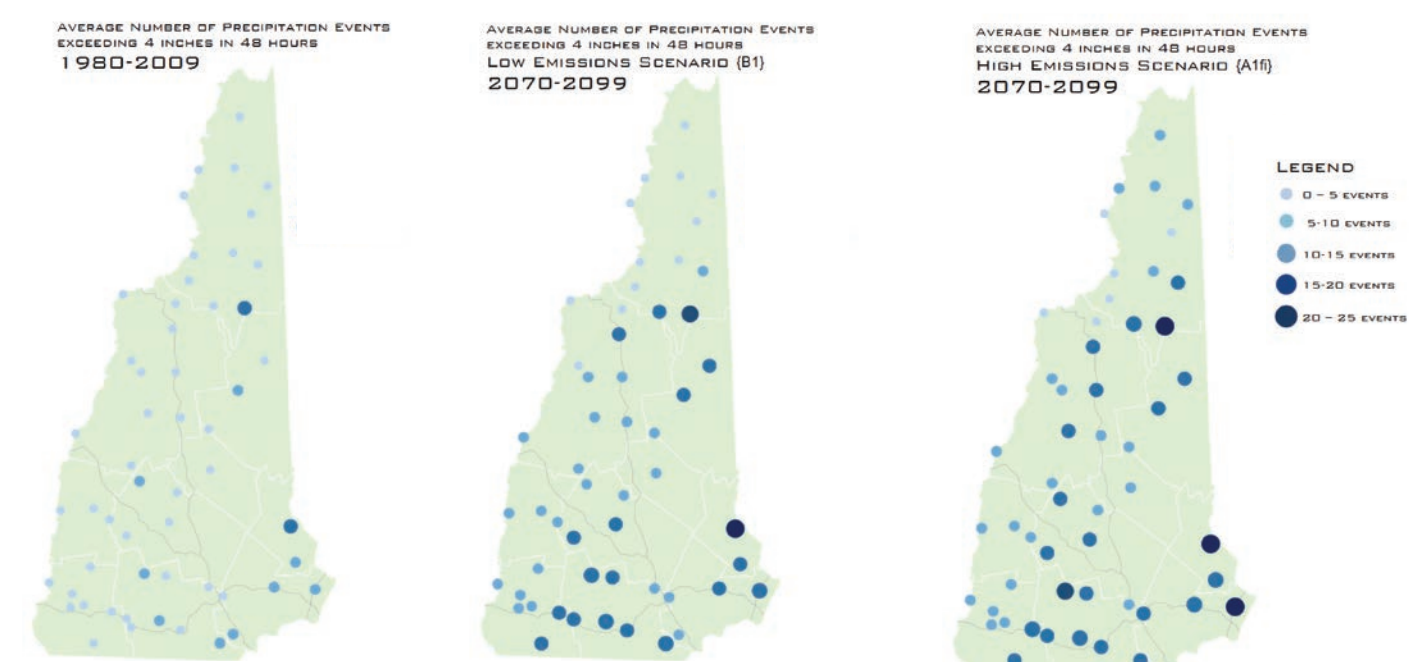


FIGURE 19. Historical (left) and projected (2070–2099) lower emissions (center) and higher emissions (right) average number of precipitation events per year that drop greater than 4 inches in 48 hours across New Hampshire.

1 inch) are examined for short- (2010–2039), medium- (2040–2069), and long-term (2070–2099) to evaluate which factor will dominate: temperature increases (which will decrease snow cover days) or precipitation increases (which would potentially increase snow cover days if the temperature remains below freezing).

Over the long-term, the influence of warming winter and spring temperatures will dominate over expected increases in winter precipitation. This means that the number of snow-covered days is projected to decrease for the rest of this century under both emissions scenarios (Figure 20; Table 9). Historically, southern New Hampshire experienced on average 105 days per year with snow cover. During the early part of the century, decreases in snow-covered days are expected to drop to 95 and 89 days for the lower and higher emissions scenarios, respectively. This trend continues through mid-century. By 2070–2099, snow-covered days are projected to number 81 days under the low emissions scenarios, and plummet to 52 days (a reduction of more than 50 percent) under the higher emissions scenario.

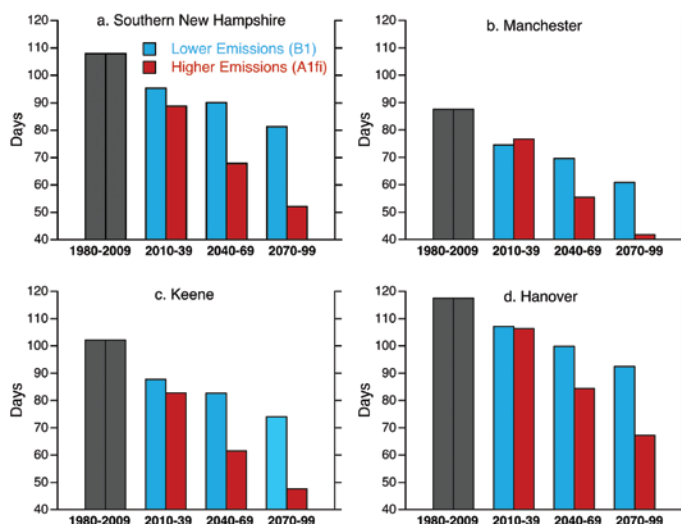


FIGURE 20. Historical (grey) and projected lower emissions (blue) and higher emissions (red) average snow-covered days (greater than 1 inch of snow), shown as 30-year averages, for a) southern New Hampshire (average of 41 stations), b) Manchester, c) Keene, and d) Hanover.

IV. HOW CAN NEW HAMPSHIRE'S COMMUNITIES RESPOND?

“America’s response to climate change is ultimately about making choices in the face of risks: choosing, for example, how, how much, and when to reduce greenhouse gas emissions and to increase the resilience of human and natural systems to climate change.”⁵⁹

The results presented in Chapters II and III of this report (with results for specific towns in southern New Hampshire summarized in Appendix B), combined with the findings of recent regional,⁶⁰ national,⁶¹ and international⁶² assessments, summarize the risks posed by climate change and provide strong motivation for assessing and implementing a wide range of proactive anticipatory and response efforts. A pressing need for significant action to limit the magnitude of climate change (via mitigation) and to prepare for its impacts (via adaptation) is clearly warranted given the environmental, economic, and humanitarian risks associated with our changing climate.⁶³

Mitigation and Adaptation

There are two broad responses for dealing with our changing climate: 1) mitigation of climate change through the reduction of emissions of heat-trapping gases and enhancing carbon sinks (for example, enhancing and preserving carbon storage in forests and soils), and 2) adaptation to the impacts of climate change, which refers to preparing and planning for climate change to better respond to new conditions, thereby reducing harm and disruption and/or taking advantage of opportunities. Mitigation and adaptation are linked; effective mitigation reduces the need for adaptation. Both are essential parts of a comprehensive dual-path response strategy.

Mitigation and adaptation at the global and continental level have been comprehensively addressed in the IPCC 2007 Working Group II (Impacts, Adaptation, and Vulnerability) and Working Group III (Mitigation of Climate Change) Fourth Assessment Reports.⁶⁴ More recent research will be summarized in the IPCC Fifth Assessment Reports from Working Groups II and III due out in the spring of 2014.⁶⁵ On the national level, a series of reports on America’s Climate Choices and the recent National Climate Assessment provide advice on the most effective steps and most promising strategies that can be taken to respond to climate change, including adaptation and mitigation efforts.⁶⁶

Effective responses aimed at reducing the risks of climate change to natural and human systems involve a portfolio of diverse adaptation and mitigation strategies. Even the most stringent mitigation efforts will not alleviate the climate change we have committed to over the next two-to-three decades (due to the long lived nature of carbon dioxide already in the atmosphere combined with the inertia within the climate system), which makes adaptation critical. Conversely, without significant mitigation efforts, a magnitude of climate change will very likely be reached that will make adaptation impossible for some natural systems, and many human systems will exact very high social and economic costs. A dual-path strategy of pursuing and integrating mitigation and adaptation strategies will reduce the negative

consequences resulting from future climate change to a far greater extent than pursuing either path alone or doing nothing at all.

Mitigation

The single most effective adaptation strategy is mitigation of climate change through the reduction of emissions of heat-trapping gases. As is clearly illustrated by the very different climate futures that result from a higher emission versus a lower emission scenario, reducing emissions of heat-trapping gases reduces the amount of change to which we have to adapt. To be effective, mitigation requires concerted efforts from individuals, communities, businesses, not-for-profits, and governments (municipal, state, and federal), locally, nationally, and abroad. Such mitigation measures range from protecting our forests and soils (for carbon sequestration) to increasing energy efficiency in buildings, electricity generation, transportation systems, and other infrastructure to increasing the amount of energy produced from renewable sources.

The New Hampshire Climate Action Plan⁶⁷ was developed via the combination of a highly collaborative process involving hundreds of diverse stakeholders, transparent quantitative analysis, and

application of decision-relevant information.⁶⁸ The plan calls for a reduction in greenhouse gas emissions of 20 percent below 1990 emissions by 2025, and 80 percent below 1990 emissions by 2050.⁶⁹ To move toward this long-term goal and provide the greatest economic opportunity to the state of New Hampshire, the Climate Action Plan recommends sixty-seven actions to:

- Reduce greenhouse gas emissions from buildings, electric generation, and transportation
- Protect our natural resources to maintain and enhance the amount of carbon sequestered
- Support regional and national initiatives to reduce greenhouse gases
- Develop an integrated education, outreach, and workforce-training program
- Adapt to existing and potential climate change impacts

These actions serve not only to reduce emissions of heat trapping gases, but also to support a wide range of economic development. In fact, following an initial investment period, almost all of the recommendations provide a net positive economic benefit to the state of New Hampshire.

The New Hampshire Energy and Climate Collaborative is tracking progress toward meeting key targets set forth in the Climate Action Plan.⁷⁰ Overall, New Hampshire has experienced a decline in overall emissions of heat-trapping gases since 2004, even while the state gross product has continued to rise (Figure 21). This separation of economic growth from emissions of heat-trapping gases is exactly what must continue if we are to achieve the vision for emissions reduction targets set out in New Hampshire's 2009 Climate Action Plan, while also providing economic opportunities for New Hampshire residents.

A few examples of successful mitigation efforts in

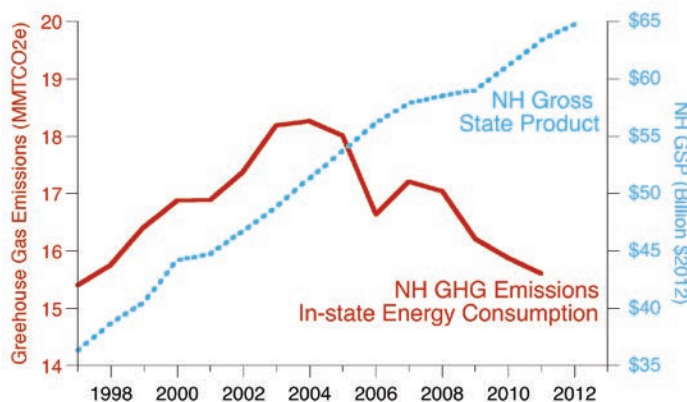


FIGURE 21. Comparison of New Hampshire's greenhouse gas emissions (red) versus its Gross State Product (GSP) (see endnote 83 for more information).

New Hampshire include the Regional Greenhouse Gas Initiative, the Greenhouse Gas Emission Reduction Fund, Better Buildings project, NH Energy Efficiency Core programs, New Hampshire Office of Energy and Planning, Jordan Institute energy efficiency projects, University of New Hampshire EcoLine, 2009 Corporate Fuel Efficiency Standards, and Revolution Energy and ReVision Energy projects.⁷¹ Additional recommendations for energy efficiency and renewable energy projects are provided in the Independent Study of Energy Policy Issues Report⁷² and subsequent New Hampshire Energy Efficiency and Sustainable Energy (ESEE) Board recommendations.⁷³

Adaptation

Adaptation is the second key component of a dual-path strategy that serves as an effective response to the risks posed by climate change. Adaptation for communities essentially involves preparing and planning for the expected impacts of climate change to avoid, manage, and/or reduce the consequences.

Climate change affects everything from transportation, infrastructure, land use, and natural resources to recreation, public health and safety, and sense of place. Fortunately for New Hampshire communities, there are opportunities for adaptation available within existing planning and regulatory processes. Virtually every community member is either a stakeholder or an implementer. Gathering and applying local knowledge concerning the impacts and consequences of weather disruption will enhance the effectiveness of local adaptation. Every community should discuss, analyze, and then determine which adaptation strategies to implement based on its specific vulnerabilities to climate change and local economic, environmental, and social conditions. Therefore, efforts to address climate change should seek input, participation, and support from all

members of your community. This may be achieved through specific outreach to neighborhoods or interest groups, municipal meetings, or through larger community events.

“Efforts to address climate change should seek input, participation, and support from all members of your community. This may be achieved through specific outreach to neighborhoods or interest groups, municipal meetings, or through larger community events.”

Adaptation strategies to protect the built environment fall into four broad categories:

No Action: To do nothing. This approach ignores the risks posed by climate change and continues a “business as usual” response.

Protect and Fortify: To keep an asset in place for a period of time. For flood protection, this commonly involves building physical barriers such as levees, berms, flood/tide gates, or sea walls. Protection is likely to be a common approach in low-lying population centers due to extensive development and investment. These strategies should be viewed as short-term solutions that do not necessarily improve community resilience (for example, when a physical barrier such as a levee fails, the impacts can be devastating).

Accommodate: To retrofit existing structures and/or design them to withstand specific extreme weather events. Freeboard requirements in building codes are a common accommodation strategy (essentially putting a building on stilts). This approach provides a safety factor and avoids damage by requiring that structures be elevated above a certain flood elevation, such as the 100-year flood elevation.

Retreat: To relocate or phase-out development in hazardous areas. In existing flood-prone areas, retreat can be the most effective and long-term solution.

While a rightly contested option, it may be best supplemented with a “wait and see” approach within areas identified as vulnerable in the future, commonly after a triggering event or when a particular threshold is reached (for example, when an asset in a high-risk area is damaged by over 50 percent of its original value and it is then relocated rather than repaired).

Adaptation actions may be implemented immediately or as iterative or delayed actions:

Here and Now: Actions taken in the near-term to build or improve existing infrastructure so that it is robust and resilient to a range of climate conditions. This approach may also involve the preparation of plans to implement future actions.

Prepare and Monitor: Options are identified to preserve assets and climate conditions are monitored so that appropriate response actions can be taken in the future.

In preparing a phased adaptive management strategy, policy and decision makers must recognize the tradeoffs between selecting one action over another (that is, investing now to protect for the long-term versus cost over time and risk associated with delaying such action). Sustained actions and investment need to be weighed against changing climate conditions over the long-term with incremental investment to protect and accommodate changing climate conditions in the short-term. Integrated actions that build upon one another to increase resiliency and decrease risk and vulnerability are preferred. Adaptation often provides both co-benefits and no-regrets actions. *Co-Benefits* refers to integrated efforts to address

climate change impacts through proactive actions and mitigation that result in building capacity, resiliency, and protection of assets and resources that can also meet economic, societal, and environmental needs. For example, preserving floodplain forests and coastal buffers provides a carbon sink (mitigation) and keeps development out of a high-risk area (proactive adaptation), while also providing benefits to wildlife, recreation, sense of place, and more. *No Regrets* refers to actions that generate direct or indirect benefits that are large enough to offset the costs of implementing the options. For example, siting new infrastructure in areas that have no or low risk of flooding today and are not projected to be flooded in the future.

Planning Framework and Approaches for Adaptation

Using the climate assessment (such as this report) as a foundation, communities should conduct a vulnerability assessment of local assets and resources that can help guide common sense and flexible adaptation strategies and recommendations for local governments, businesses, and citizens to enable them to implement appropriate programs, policies, regulations, and business practices (Figure 22). Analysis and data from a vulnerability assessment can help identify priority assets, actions, and planning needs or identify deficits in data, information, or processes necessary to move forward in adapting to climate change. Once the vulnerability assessment is complete, communities should develop a flexible, staged, adaptation plan that is periodically updated and designed to be easily integrated into



FIGURE 22. Key steps for moving from a climate assessment to local and regional adaptation plans.

existing plans, policies, or practices. Communities also need to ensure that future development is consistent with the plan.

The Granite State Future project has developed a framework for the range of planning issues for New Hampshire communities as they prepare for and respond to climate change.⁷⁴ Material culled from that document relating to community planning is provided below.

“Using the climate assessment as a foundation, communities should then conduct a vulnerability assessment of local assets and resources that can help guide common sense and flexible adaptation strategies and recommendations for local governments, businesses, and citizens to enable them to implement appropriate programs, policies, regulations, and business practices.”

To leverage the effectiveness and benefits of climate adaptation, key strategies and actions should be institutionalized across all levels of regional and local planning. As a matter of efficiency and practicality, planning for climate change should utilize existing plans, policies, and practices with the goal of reorienting them using the “climate lens” to incorporate future projected conditions or the new climate normal. Because state statute gives municipalities broad authority to regulate, significant components of climate adaptation planning will occur at the local level. To accomplish this, effective adaptation planning should seek to:

- Identify vulnerable assets and resources
- Guide planning, regulation, and policies at all scales
- Inform prioritization of state, regional, and private investments in areas at risk to future conditions
- Identify possible strategies and actions that provide economic, social, and environmental benefits
- Protect public health and safety

- Improve community awareness about the region’s changing climate
- Preserve regional and community character and ensure sustainable outcomes

Planning Strategies

Ultimately, planning for climate change means using the wide range of planning tools and procedures available to integrate climate adaptation across all sectors. Just as the dual path of mitigation and adaptation are central to addressing climate change, a comprehensive multi-pronged planning approach is critical for ensuring that decisions are balanced, equitable, and long-lasting. It is equally important to recognize the values and benefits that ecosystem services provide for human enjoyment and survival. However, inevitably “tradeoffs” will be necessary to achieve desired goals and priorities. Following are examples of planning strategies that support comprehensive and effective implementation of climate adaptation. Many of these strategies can easily be combined or include mitigation strategies.

- Integrate planning for transportation, land use, human health, natural resources, and ecosystem services
- Integrate zoning, land use, and resource conservation—environmental and floodplain regulation, conservation subdivision incentives in high-risk areas, village center zoning, transfer of development rights, open space, and land preservation
- Encourage Sustainability and Smart Growth planning (mixed use development and village development, conservation/open space subdivision, alternative transportation access, and preservation of agricultural lands)
- Conduct a Municipal Audit to identify barriers and incentives to implement climate change planning and adaptation at the local level (zoning, regulations, and master plan)

- Encourage integration of climate change into local plans—master plans, hazard mitigation plans, open space/land conservation plans, and regional health assessments
- Adopt long-range infrastructure investments and improvements into capital improvement plans (CIPs) and maintenance plans
- Encourage municipal participation in the FEMA Community Rating System⁷⁵ to reduce flood insurance premiums
- Encourage cooperative agreements among municipalities (that is, for water and sewer services; equipment and inspectional staff/consultants; and integrated transportation, land use, and environment planning)
- Community participation and support (warrant articles, budget, and voluntary stewardship)
- Develop an action plan for regional implementation of recommended actions from the NH Climate Action Plan

Community Engagement and Laying the Foundation for Implementation

This section provides examples of how some New Hampshire communities have begun discussions and planning around adaptation. They also provide examples of external expertise and other support that is available.

Dover: Climate Change Role Play Simulation⁷⁶

City officials and project partners gathered area residents to participate in a series of “climate change games,” wherein people experience the challenge of negotiating through climate change planning while playing the role of a city official or resident. The goal of this effort was to assess local climate change risks, identify key challenges and opportunities for adaptation, and to test the use of role-play simulations

as a means to engage the community about climate change threats while exploring ways of decreasing its vulnerability to climate change impacts. Dover was one of four towns participating in the National Oceanic and Atmospheric Administration (NOAA) funded New England Climate Adaptation Network.

Hampton, Hampton Falls, and Seabrook: Planning for Sea Level Rise⁷⁷

With funding support from EPA’s Climate Ready Estuaries Program, three communities of the Hampton-Seabrook Estuary used a cost-benefit analysis tool to evaluate potential impacts from storm surge and sea level rise to private real estate and public facilities. This effort considered lower and higher global emission and resulting climate change scenarios, the costs and benefits of taking action, and when it makes the most sense to implement adaptation strategies. As a result of their collaborative approach, the communities identified shared concerns and priorities such as preserving marshes to buffer shorefront properties from coastal storms, and a need to further consider climate change as a three-town working group.

Newfields: Extreme Weather Preparedness Action Plan⁷⁸

The small coastal town of Newfields developed an extreme weather preparedness action plan. To begin, local leaders convened over thirty-five community members for dinner and discussion following a presentation of local climate change research from the University of New Hampshire. This information formed the basis for a series of small roundtable discussions about: (1) how extreme weather affects the people of Newfields and their natural resources and infrastructure, and (2) what possible actions the town could take to reduce these impacts. Two focus areas emerged (stormwater management and emergency preparedness), and community members continued

to meet for six months to finalize an action plan to increase resiliency.

As a result, the town developed and immediately began implementing eighteen action items, including a discount generator purchase program led by the Chief of Police and an updated stormwater management regulation led by the planning board.

Exeter: Climate Adaptation Plan⁷⁹

The Climate Adaptation Plan for Exeter (CAPE) initiative aspires to create a flexible science-based plan for managing local impacts to infrastructure, public safety, and natural resources (for example, fisheries, stormwater, and water quality). Residents and leaders of the “Citizens Working Group” worked closely with the science team to ensure the plan was informed by local concerns and priorities. The broader community was engaged periodically through large “community conversation” gatherings and presentations to town boards.

Durham: Climate Adaptation Chapter for Hazard Mitigation Plan⁸⁰

The Town of Durham’s “Leadership Team” developed a climate adaptation chapter for its Hazard Mitigation Plan. The plan provides a broad overview assessment of likely impacts from sea level rise and areas likely to experience future increases in flooding. The plan also outlines over a dozen regulatory and non-regulatory approaches appropriate for the community to take as next steps.

Lamprey River Watershed: Assessing Flood Risk⁸¹

Both the magnitude and frequency of freshwater flooding is on the rise in seacoast New Hampshire and around much of New England. This NOAA-funded research and outreach project analyzed changes in the extent of the 100-year floodplain in the Lamprey

River watershed and projected future changes based on different scenarios of land use and climate change. The results clearly show that the 100-year floodplain and associated peak flood water discharge, as well as flood water surface elevations, have increased significantly between the production of the effective Flood Insurance Rate Maps (FIRMs, based on discharge data from 1935–1987) to current (2005) conditions, and will continue to increase in the future under the build-out scenarios developed as part of this research. Low impact development zoning was shown to have its greatest mitigation value in terms of resiliency in high impervious cover areas. This increase in the 100-year floodplain and 100-year flood discharge has important ramifications for natural resources, human well-being, emergency management, planning, and infrastructure. In addition, the risk of municipal legal liability associated with using the new 100-year floodplain maps is low, so long as municipalities follow sound planning principles.

City of Portsmouth, Coastal Resiliency Initiative⁸²

The Coastal Resilience Initiative is the City of Portsmouth’s first look at the potential impact from a changing climate focusing on impacts of sea level rise and coastal storm surge. The objectives of the study were to:

- Describe the range of climate change and sea level rise scenarios that researchers have identified for the New Hampshire Seacoast region
- Map four sea level elevations to show how these scenarios would impact the City of Portsmouth in the next forty to ninety years
- Using these maps, identify physical assets (buildings and infrastructure) and natural resources that are vulnerable to sea level rise and coastal storm surge

- Develop preliminary strategies for adapting to future conditions, as well as estimates of the costs of these adaptation actions
- Provide recommendations to guide adaptation planning, including policies and regulations

The study products include a set of flood elevation maps, a vulnerability assessment, a preliminary outline of potential adaptation strategies, and recommendations for future planning, regulation, and policies. This report represents a starting point for the city to identify avenues to implement adaptation measures that impart resiliency in the built environmental and protect natural systems.

Keene Cities for Climate Protection (CPC) Committee⁸³

The Keene City Council officially created the CPC Committee in 2000. Its mission is to aid in the reduction of greenhouse gas emissions and increase the community's adaptive capacity to the expected impacts of a changing climate in order to protect the viability of the community and to protect public health, safety, and welfare. The city has adopted both a Climate Change Action Plan and a Climate Change Adaptation Action Plan, both of which are being implemented.

ADDITIONAL RESOURCES FOR ADAPTATION TO CLIMATE CHANGE

The [Adaptation Toolkit for New Hampshire Communities⁸⁴](#) provides communities with a path to plan for future extreme weather events.

The [Climate Adaptation Knowledge Exchange⁸⁵](#) features a vast library of concise case studies of climate adaptation from around the country and the world. It also provides links to funding sources for adaptation.

[Extreme Precipitation in New York and New England⁸⁶](#) provides an updated extreme precipitation analysis via an interactive web tool. [Forging the Link: Linking the Economic Benefits of Low Impact Development and Community Decisions⁸⁷](#) documents, through a series of case studies, the advantages of Low Impact Development in the economic terms of how municipal land use decisions are commonly made.

The [Georgetown Climate Center⁸⁸](#) provides resources to help communities prepare for climate change, including the Adaptation Clearinghouse, Adaptation Tool Kits, lessons learned, and case studies.

[Home Grown: The Economic Impact of Local Food Systems in New Hampshire⁸⁹](#) seeks to provide an answer to the question: What are local, healthy foods, and the food system that supports them, worth?

[The Infrastructure and Climate Network⁹⁰](#) (ICNet) is dedicated to accelerating climate science and engineering research in the Northeastern United States. It focuses on climate change and sea level rise impacts and adaptation for sustainable bridges, roads, and transportation networks.

ADDITIONAL RESOURCES FOR ADAPTATION TO CLIMATE CHANGE (CONTINUED)

[New Hampshire Building Energy Code](#)

[Compliance Roadmap Report](#)⁹¹ maps out New Hampshire's existing energy code landscape, identifies barriers to energy code compliance across the state's residential and commercial building sectors, and presents a plan outlining New Hampshire-specific recommendations for achieving 90 percent energy code compliance by 2017.

[NH Granit](#)⁹² is New Hampshire's Statewide Geographic Information System Clearinghouse. It offers an array of geospatial services, including: data development and distribution, spatial analysis, online mapping (including 100-year flood plain maps), cartography, and related technical services.

[New Hampshire Lives on Water](#)⁹³ is the final report of the New Hampshire Water Sustainability Commission and makes recommendations to ensure that the quality and quantity of New Hampshire's water in twenty-five years is as good as or better than it is today.

[New Hampshire Local Energy Solutions](#)⁹⁴ provides a gateway to information and resources that promote local energy solutions in New Hampshire. It is intended to empower those on energy committees, in municipalities, and schools to tackle the complexities of reducing our reliance on fossil fuel energy.

[New Hampshire Office of Energy and Planning—](#)

[Cost of Sprawl Tool](#)⁹⁵ has been designed as a decision-support tool for New Hampshire's local and regional planners to evaluate the financial impact on local governments related to new development.

[New Hampshire's Changing Landscape](#)⁹⁶ explores the relationships between population growth, land use change, and the impact of development upon the state's natural resources, including our forest and agricultural lands, critical water supply resources, and biodiversity.

The [New Hampshire Storm Smart Coast](#)⁹⁷ provides a well developed example of a web resource dedicated to helping community decision makers address the challenges of storms, flooding, sea level rise, and climate change. The website also features efforts by the NH Coastal Adaptation Workgroup (NHCAW), a collaboration of nineteen organizations working to help communities in New Hampshire's Seacoast area prepare for the effects of extreme weather events and other effects of long-term climate change. NHCAW provides communities with education, facilitation, and guidance.

[Transportation and Climate Change](#)

[Clearinghouse](#)⁹⁸ is the U.S. Department of Transportation website that provides information on transportation and climate change.

The [Upper Valley Adaptation Workgroup](#)⁹⁹ is building climate resilient communities in the Upper Valley through research, information sharing, and education.

V. CONCLUSIONS

An extensive and growing body of scientific evidence clearly shows that global climate is changing, and that human activities are the primary driver of that change over the past four decades. Climate change is already affecting the northeast United States and southern New Hampshire in many ways. Temperatures have begun to rise, particularly in winter. Precipitation is increasing, as is the frequency of extreme precipitation events. Lake ice-out dates are occurring earlier.

These and many other trends are projected to continue in the future. With few exceptions, much greater changes are anticipated under a higher emissions scenario as compared to a lower emissions scenario. In other words, depending on the amount of heat trapping gases that human activities pump into the atmosphere, annual average temperatures in southern New Hampshire could increase between 4°F and 9°F before the end of the twenty-first century. Warmer temperatures mean increased frequency of extreme heat events and decreases in extreme cold and days. Precipitation, especially in winter and spring, is expected to rise, as is the frequency of extreme precipitation events, exacerbating the risk of flooding. Snow-covered days are expected to decrease.

Because climate change is already affecting southern New Hampshire, and some additional warming is inevitable, it is essential to prepare to adapt to the changes that cannot be avoided. However, immediate and committed action to reduce emissions is the most effective means to keep future climate changes at those projected under the lower emissions scenario. The more we can reduce our fossil fuel emissions, the more ecosystems, human communities, and economic sectors will be able to adapt to those coming changes we cannot avoid.

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APPENDIX A. METHODS

Historical Climate Change

To quantify historical trends in temperature and precipitation across New Hampshire, we used data from two high-quality meteorological data sets. Monthly temperature and precipitation observations for the time period 1895–2012 for three stations across southern New Hampshire (Figure 1; Hanover, Durham, and Keene) come from the U.S. Historical Climatology Network (USHCN) Version 2.5.¹⁰⁰ The observations from the USHCN data sets have been subjected to numerous quality assurance and quality control procedures that have corrected temperature records for time-of-observation biases and other non-climatic changes such as station relocations, instrument changes, changes in observer, and urban heat island effects through homogeneity testing.¹⁰¹

Daily temperature and precipitation observations are available for many stations across New Hampshire from the Global Historical Climatology Network-Daily (GHCN-Daily) Version 3.02-upd-2013051005¹⁰²; these daily temperature records have been subjected to a number of quality assurance and quality control procedures¹⁰³ and have been homogenized.¹⁰⁴ We only used GHCN-Daily data for stations that had near complete records for the time period 1960–2012 (meteorological data from the GHCN-Daily data set prior to 1960 for New Hampshire were limited). For temperature and total precipitation, we excluded a year of data from our analysis if more than 10 percent of the data were missing for that year for a particular station. We also excluded the entire station from our analysis if more than 10 percent of the years were

missing. For snowfall and snow covered days, the criteria we used for temperature eliminated all of the stations from our analysis. We therefore used different criteria for records of snowfall and snow-covered days: we excluded a year of data from our analysis if more than 20 percent of the data was missing for that year for a particular station. We also excluded the entire station from our analysis if more than 20 percent of years were missing.

All of the data we used in our analysis of historical climate trends across New Hampshire are available from the New Hampshire Experimental Program to Stimulate Competitive Research (EPSCoR)—Data Discover Center.¹⁰⁵

All historical climate trends are calculated using Sen's slope¹⁰⁶ and expressed as change in units per decade. Sen's estimation of slope is succinctly described as the median slope of all possible slopes in an evenly spaced time series. As such, it provides a more robust trend estimation than the commonly used least squares linear regression, which may be sensitive to the start and end dates in a time series. The statistical significance of the slope is evaluated using the Mann-Kendall non-parametric test. Trends are considered statistically significant if $p < 0.05$.

Historical Global Climate Model (GCM) Simulations and Future Emission Scenarios

Historical climate model simulations use external forcings or climate drivers (including atmospheric levels of greenhouse gases, solar radiation, and volcanic eruptions) consistent with observed values

for each year of the simulation. The historical forcings used by the GCM simulations presented in this report are the Coupled Model Intercomparison Project's "20th Century Climate in Coupled Models" or 20C3M total forcing scenarios.¹⁰⁷ These simulations provide the closest approximation to actual climate forcing from the beginning of the historical simulation to the year 2000.

The historical simulation provides the starting conditions for simulations of future climate. To ensure the accuracy of the historical forcing scenario, it is customary in the climate modeling community for historical simulations to end at least five years before present. So although the GCM simulations were typically conducted after 2005, the historical total-forcing scenario ends and "future" scenarios begin in 2000. In the future scenarios, most external natural climate drivers are fixed, and human emissions correspond to a range of plausible pathways rather than observed values.

Future emissions scenarios depend on a myriad of factors, including: how human societies and economies develop over the coming decades; what technological advances are expected; which energy sources will be used in the future to generate electricity, power, transportation, and serve industry; and how all of these choices affect future emissions from human activities.

To address these questions, in 2000 the Intergovernmental Panel on Climate Change (IPCC) developed a series of scenarios described in the Special Report on Emissions Scenarios (SRES).¹⁰⁸ These scenarios describe internally consistent pathways of future societal development and corresponding emissions.

This analysis used the SRES emission scenarios A1fi higher and B1 lower emissions scenarios (Figure A1). These scenarios were chosen because they cover a broad range of plausible futures in terms of human emissions of carbon dioxide and other

radiatively active species and resulting impacts on climate. At the higher end of the range, the SRES high emissions or fossil fuel intensive scenario (A1fi for *fossil-intensive*) represents a world with fossil fuel-intensive economic growth and a global population that peaks mid-century and then declines. New and more efficient technologies are introduced toward the end of the century. In this scenario, atmospheric CO₂ concentrations reach 940 parts per million by 2100, more than triple pre-industrial levels of 280 ppm. At the lower end, the SRES low emissions scenario (B1) also represents a world with high economic growth and a global population that peaks mid-century and then declines. However, this scenario includes a shift to less fossil fuel-intensive industries and the introduction of clean and resource-efficient technologies. Emissions of greenhouse gases peak around mid-century and then decline. Atmospheric carbon dioxide levels reach 550 parts per million by 2100, about double pre-industrial levels. Associated global temperature changes by end-of-century range from 4 to 9°F based on the best estimate of climate sensitivity.

As diverse as they are, the SRES scenarios do not cover the entire range of possible futures. Since 2000,

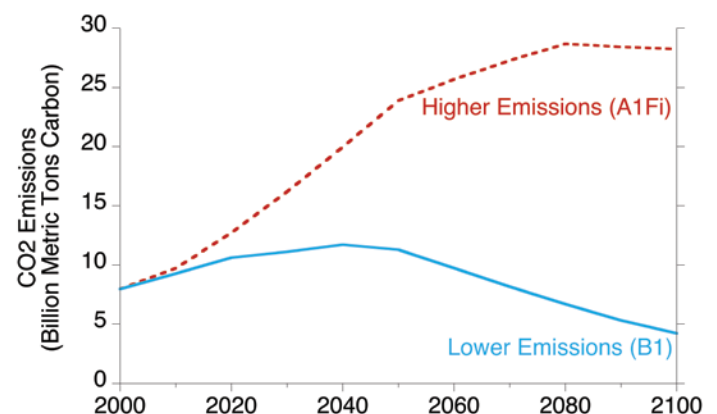


FIGURE A1. Projected future global emissions of carbon dioxide from fossil fuel burning for the "high emissions" (A1fi, red) and "low emissions" (B1, blue) scenarios. Data from Nakicenovic, et al. (2000).

CO₂ emissions have already been increasing at an average rate of 3 percent per year. If they continue at this rate, emissions will eventually outpace even the highest of the SRES scenarios.¹⁰⁹ On the other hand, significant investments in renewable energy and energy efficiency could reduce CO₂ emissions below the lower B1 emission scenario within a few decades.¹¹⁰ Nonetheless, the substantial difference between the high- versus the low-emission scenarios used here provides a good illustration of the potential range of changes that could be expected, and how much these depend on future emissions and human choices.

Global Climate Models (GCMs)

Future emission scenarios are used as input to GCMs, complex, three-dimensional coupled models that continually evolve to incorporate the latest scientific understanding of the atmosphere, oceans, and Earth's surface. As output, GCMs produce geographic grid-based projections of temperature, precipitation, and other climate variables at daily and monthly scales. These physical models were originally known as atmosphere-ocean general circulation models (AO-GCMs). However, many of the newest generation of models are now more accurately described as GCMs as they incorporate additional aspects of the Earth's climate system beyond atmospheric and oceanic dynamics.

Because of their complexity, GCMs are constantly being enhanced as scientific understanding of climate improves and as computer computational power increases. Some models are more successful than others at reproducing observed climate and trends over the past century.¹¹¹ However, all future simulations agree that both global and regional temperatures will increase over the coming century in response to increasing emissions of heat-trapping gases from human activities.¹¹²

Historical GCM simulations are initialized in the late 1800s, externally “forced” by the human emissions, volcanic eruptions, and solar variations represented by the historical 20C3M scenario described above. They are also allowed to develop their own pattern of natural chaotic variability over time. This means that, although the climatological means of historical simulations should correspond to observations at the continental to global scale, no temporal correspondence between model simulations and observations should be expected on a day-to-day or even year-to-year basis. For example, while a strong El Niño event occurred from 1997 to 1998 in the real world, it may not occur in a model simulation in that year. Over several decades, however, the average number of simulated El Niño events should be similar to those observed. Similarly, although the central United States suffered the effects of an unusually intense heat wave during the summer of 1995, model simulations for 1995 might show that year as average or even cooler-than-average. However, a similarly intense heat wave should be simulated some time during the climatological period centered around 1995.

In this study, we used GCM simulations archived by the Program for Climate Model Diagnosis and Intercomparison (PCMDI). This collection of climate model simulations, assembled between 2005 and 2006, consists of models that contributed to phase three of the Coupled Model Intercomparison Project (CMIP3)¹¹³ and were the basis for results presented in the 2007 IPCC Fourth Assessment Reports.¹¹⁴ The CMIP3 GCM simulations used in this project consist of all model outputs archived by PCMDI with daily maximum and minimum temperature and precipitation available for the SRES A1fi and B1 scenarios. Additional simulations were obtained from the archives of the Geophysical Fluid Dynamics Laboratory, the National Center for Atmospheric Research, and the U.K. Meteorological Office. The list of GCMs used, their

origin, the scenarios available for each, and their equilibrium climate sensitivity are provided in Table A1.¹¹⁵

We chose the GCMs used in this study based on several criteria. First, only well-established models were considered—those already extensively described and evaluated in the peer-reviewed scientific literature. Models had to be evaluated and shown to adequately reproduce key features of the atmosphere and ocean system. Second, the models had to include the greater part of the IPCC range in climate sensitivity. Climate sensitivity is defined as the temperature change resulting from a doubling of atmospheric carbon dioxide concentrations relative to pre-industrial times, after the atmosphere has had decades to adjust to the change. In other words, climate sensitivity determines the extent to which temperatures rise under a given increase in atmospheric concentrations of greenhouse gases.¹¹⁶ The third and final criterion is that the models chosen must have continuous daily time series of temperature and precipitation archived for the global emission scenarios used here (SRES A1fi and B1). The GCMs selected for this analysis are the only models that meet these criteria.

For some regions of the world (including the

Arctic, but not the continental United States), there is evidence that models better able to reproduce regional climate features may produce different future projections.¹¹⁷ Such characteristics include large-scale circulation features or feedback processes that can be resolved at the scale of a global model. However, it is not valid to evaluate a global model on its ability to reproduce local features, such as the bias in temperature over a given city or region. Such limitations are to be expected in any GCM, as they are primarily the result of a lack of spatial resolution rather than any inherent shortcoming in the physics of the model. Here, no attempt was made to select a sub-set of GCMs that performed better than others, as previous literature has shown that it is difficult, if not impossible, to identify such a sub-set for the continental United States.¹¹⁸

Statistical Downscaling Model

Global climate models (GCMs) cannot accurately capture the fine-scale changes experienced at the regional to local scale. GCM simulations require months of computing time, effectively limiting the typical grid cell sizes of the models to one or more degrees per side. And, although the models are precise to this scale, they are actually skillful, or accurate, to an even coarser scale.¹¹⁹

Dynamical and statistical downscaling represent two complimentary ways to incorporate higher-resolution information into GCM simulations in order to obtain local- to regional-scale climate projections. Dynamical downscaling, often referred to as regional climate modeling, uses a limited-area, high-resolution model to simulate physical climate processes at the regional scale, with grid cells typically ranging from 4 to 50 km per side. Statistical downscaling models capture historical relationships between large-scale

Origin	Model	Scenarios	Equilibrium Climate Sensitivity (°C)*
National Center for Atmospheric Research, USA	CCSM3	A1fi, B1	2.7
National Center for Atmospheric Research, USA	PCM	A1fi, B1	2.1
Geophysical Fluid Dynamics Laboratory, USA	GFDL CM2.1	A1fi, B1	3.4
UK Meteorological Office Hadley Centre	HadCM3	A1fi, B1	3.3

*data from IPCC 2007 Fourth Assessment Report, Chapter 8.

TABLE A1. Coupled Model Intercomparison Project 3 (CMIP3) global climate modeling groups and their Global Climate Models (GCMs) used in this analysis for generating projections of future climate change. The HadCM3 model only has 360 days per year. All other models archived full daily time series from 1960 to 2099.

weather features and local climate, and they use these to translate future projections down to the scale of any observations—here, to individual weather stations.

Statistical models are generally flexible and less computationally demanding compared to regional climate models and are able to use a broad range of GCM inputs to simulate future changes in temperature and precipitation for a continuous period covering more than a century. Hence, statistical downscaling models are best suited for analyses that require a range of future projections reflecting the uncertainty in future emissions scenarios and climate sensitivity, at the scale of observations that may already be used for planning purposes. If the study is more of a sensitivity analysis, where using only one or two future simulations is not a limitation, or if it requires multiple surface and upper-air climate variables as input and has ample financial resources to support multi-year analyses, then regional climate modeling may be more appropriate.

In this project, we used a relatively new statistical downscaling model, the Asynchronous Regional Regression Model (ARRM).¹²⁰ Our analysis expands on original applications with modifications specifically aimed at improving the ability of the model to simulate the shape of the distribution including the tails, the use of a piecewise rather than linear regression to accurately capture the often non-linear relationship between modeled and observed quantiles, and bias correction at the tails of the distribution. It is a flexible and computationally efficient statistical model that can downscale station-based or gridded daily values of any variable that can be transformed into an approximately symmetric distribution and for which a large-scale predictor exists. A quantile regression model is derived for each individual weather station that transforms historical model simulations into a probability distribution that closely resembles historical observations (Figure A2a). This model can

then be used to transform future model simulations into distributions similar to those observed (Figure A2b).

Both statistical and dynamical downscaling models are based on a number of assumptions, some shared, some unique to each method. Two important shared assumptions are the following: first, that the inputs received from GCMs are reasonable (that is, they adequately capture the large-scale circulation of the atmosphere and ocean at the skillful scale of the

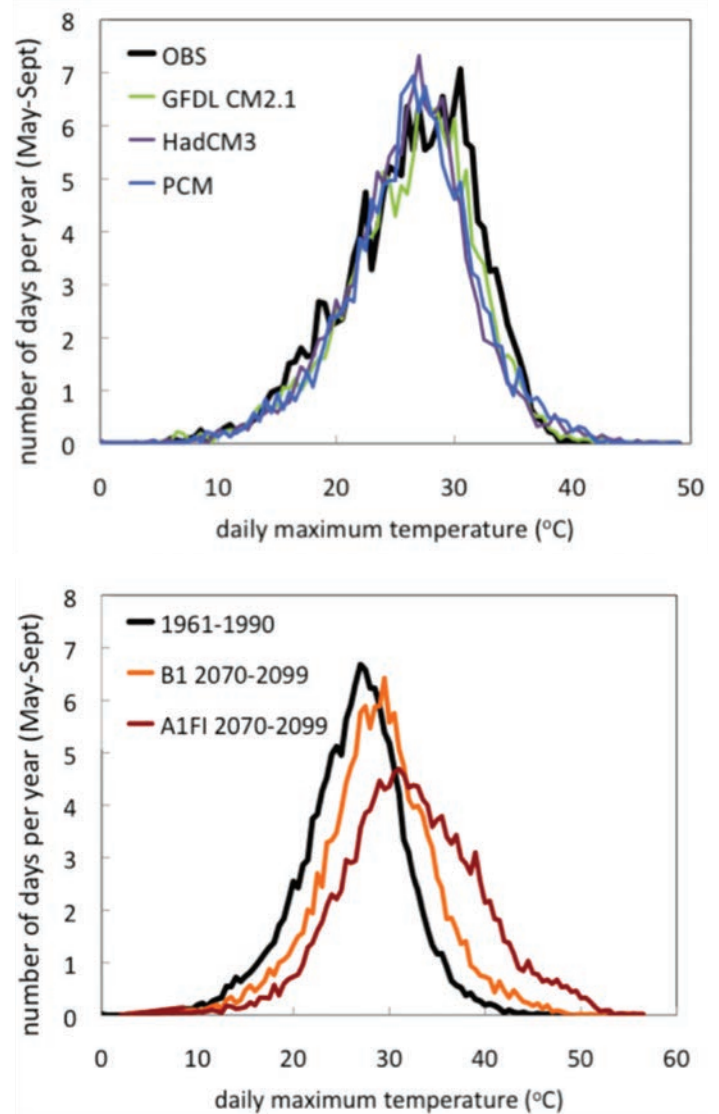


FIGURE A2. (a) Observed (black) and historical simulated distribution of daily maximum summer temperatures by three Global Climate Models for a weather station in Chicago for evaluation period 1980–1999 (top); (b) historical simulated (black) and future projected daily maximum summer temperature under the A1Fi higher (red) and B1 lower (orange) emission scenarios (bottom).

global model); and second, that the information from the GCM fully incorporates the climate change signal over that region. In addition, all statistical models are based on a crucial assumption often referred to as stationarity. Stationarity assumes that the relationship between large-scale weather systems and local climate will remain constant over time. This assumption may be valid for lesser amounts of change, but could lead to biases under larger amounts of climate change.¹²¹

In a separate project, we are currently evaluating the stationarity of three downscaling methods, including the ARRM method used here. Preliminary analyses show that the assumption of stationarity holds true over much of the world for the lower and middle of the distribution. The only location where ARRM performance is systematically non-stationary is at high temperatures (at and above the 99.9th quantile) along coastal areas, with warm biases up to 6°C. (This bias is therefore only important for days hotter than the 1-in-1000 historical day, so in other words days that historically occur no more than one day every 2.7 years.) This may be due to the statistical model's inability to capture dynamical changes in the strength of the land-sea breeze as the temperature differences between land and ocean are exacerbated under climate change; the origins of this feature are currently under investigation. For precipitation, the ARRM method is characterized by a spatially variable bias at all quantiles that is generally not systematic, and varies from approximately -30 to +30 percent for higher quantiles of precipitation (above the 90th percentile) depending on location.

The methods used to statistically downscale GCM simulation using asynchronous quantile regression are described in detail in a published paper.¹²² In terms of training the downscaling model using meteorological data from New Hampshire weather stations, the observed record must have an adequate length and quality of data. A minimum of twenty consecutive

years of daily observations with less than 5 percent missing data is commonly required in order to appropriately sample from the range of natural climate variability at most of the station locations examined. Here, downscaling was conducted using the entire record from 1960 to 2012 to include as broad a range of observed variability as possible. Downscaling was conducted and tested using observed daily minimum and maximum temperature for twenty-five GHCN-Daily stations in southern New Hampshire (south of latitude 43.9 N; Table 7; Figure 10) and observed 24-hour cumulative precipitation for forty-one GHCN-Daily stations in southern New Hampshire (Table 8; Figure 11). Although GHCN-Daily station data have already undergone a standardized quality control,¹²³ before using the station data for downscaling, they were filtered using a quality control algorithm to identify and remove erroneous values previously identified in the GHCN database. This additional quality control step included three tests for errors, removing 1) data on any days where the daily reported minimum temperature exceeded the reported maximum, 2) any temperature values above (below) the highest (lowest) recorded values for North America, or with precipitation below zero or above the highest recorded value for the state of New Hampshire, and 3) repeated values of more than five consecutive days with identical temperature or non-zero precipitation values to the first decimal.

Addressing Uncertainty

The primary challenge of a climate assessment is the reliability of information concerning future climate. A common axiom warns that the only aspect of the future that can be predicted with any certainty is the fact that it is impossible to do so. However, although it is not possible to predict the future, it is possible to project it. Projections can describe what is likely to occur under a set of consistent and clearly articulated

assumptions. For climate change, these assumptions should encompass a broad variety of the ways in which energy, population, development, and technology might change in the future.

There is always some degree of uncertainty inherent in any future projections. In order to accurately interpret and apply future projections for planning purposes, it is essential to quantify both the magnitude of the uncertainty as well as the reasons for its

“A common axiom warns that the only aspect of the future that can be predicted with any certainty is the fact that it is impossible to do so. However, although it is not possible to predict the future, it is possible to project it.”

existence. Each of the steps involved in generating projections—future scenarios, global modeling, and downscaling—introduces a degree of uncertainty into future projections; how to address this uncertainty is the focus of this section.

Another well-used axiom states that all models are wrong, but some models are useful. The Earth’s climate is a complex system. It is only possible to simulate those processes that have been observed and documented. Clearly, there are other feedbacks and forcing factors at work that are challenging to capture or have yet to be documented. Hence, it is a common tendency to assign most of the range in future projections to model, or scientific, uncertainty.

Future projections will always be limited by scientific understanding of the system being predicted. However, there are other important sources of uncertainty that must be considered—some that even outweigh model uncertainty for certain variables and time scales. Uncertainty in climate change at the global to regional scale arises primarily due to three different causes: (1) natural variability in the climate system, (2) scientific uncertainty in predicting the response of

the Earth’s climate system to human-induced change, and (3) socio-economic or scenario uncertainty in predicting future energy choices and hence emissions of heat-trapping gases.¹²⁴

Scenario uncertainty is very different, and entirely distinct, from scientific uncertainty in at least two important ways. First, while scientific uncertainty can be reduced through coordinated observational programs and improved physical modeling, scenario uncertainty arises due to the fundamental inability to predict future changes in human behavior. It can only be reduced by the passing of time, as certain choices (such as depletion of a non-renewable resource) can eliminate or render certain options less likely. Second, scientific uncertainty is often characterized by a normal distribution, where the mean value is more likely than the outliers. Scenario uncertainty, however, hinges primarily on whether or not the primary emitters of heat-trapping gases, including traditionally large emitters such as the United States and nations with rapidly-growing contributions such as India and China, will enact binding legislation to reduce their emissions. If they do enact legislation, then the lower emission scenarios become more probable. If they do not, then the higher emission scenarios become more probable. The longer such action is delayed, the less likely it becomes to achieve a lower emissions scenario because of the emissions that continue to accumulate in the atmosphere. Consequently, scenario uncertainty cannot be considered to be a normal distribution. Rather, the consequences of a lower versus a higher emissions scenario must be considered independently, in order to isolate the role that human choices are likely to play in determining future impacts.

Over timescales of years to several decades, natural chaotic variability is the most important source of uncertainty (Figure A3). By mid-century, scientific or model uncertainty is the largest contributor to the range in projected temperature and precipitation

change. By the end of the century, scenario uncertainty is most important for temperature projections, while model uncertainty continues as the dominant source of uncertainty in precipitation. This is consistent with the results of the projections discussed in this report, where there is a significant difference between the changes projected under high versus low emission scenarios for temperature-based and heavy precipitation indicators, but little difference for mean precipitation-based indicators.

The first source of uncertainty can be addressed by always averaging or otherwise sampling from the statistical distribution of future projections over a climatological period—typically, twenty to thirty years. In other words, the average winter temperature should be averaged over several decades, as should the coldest day of the year. No time stamp more precise than twenty to thirty years should ever be assigned to any future projection. In this report and accompanying data files, simulations are always averaged over four thirty-year climatological time periods: historical (1980–2009), near-term (2010–2039), mid-century (2040–2069), and end-of-century (2070–2099).

The second source of uncertainty, model or scientific uncertainty, can be addressed by using multiple global climate models to simulate the response of the climate system to human-induced change. As noted above, the climate models used here cover a range of climate sensitivity (Table A1); they also cover an even wider range of precipitation projections, particularly at the local to regional scale. Only models that demonstratively fail to reproduce the basic features of large-scale climate dynamics (for example, the Jet Stream or El Niño) should be eliminated from consideration. Multiple studies have convincingly demonstrated that the average of an ensemble of simulations from a range of climate models (even ones of varied ability) is generally closer to reality than the simulations from one individual

model, even one deemed “good” when evaluated on its performance over a given region.¹²⁵ Hence, wherever possible, impacts should be summarized in terms of the values resulting from multiple climate models, while uncertainty estimates can be derived from the range or variance in model projections. This is why all plots and tables in this report show multi-model mean values.

The third and final primary source of uncertainty in future projections can be addressed through generating climate projections for multiple futures: for example, a “higher emissions” future where the world continues to depend on fossil fuels as the primary energy source (SRES A1fi), as compared to a “lower emissions” future focusing on sustainability and conservation (SRES B1).

Over the next two-to-three decades, projections can be averaged across emission scenarios as there is no significant difference between scenarios over that time frame due to the inertia of the climate system in responding to changes in heat-trapping gas levels in the atmosphere.¹²⁶ Past mid-century, however, projections should never be averaged across scenarios; rather, the difference in impacts resulting from a higher as compared to a lower scenario should always be clearly delineated. That is why, in this report, future projections are always summarized in terms of what is expected for each scenario individually.

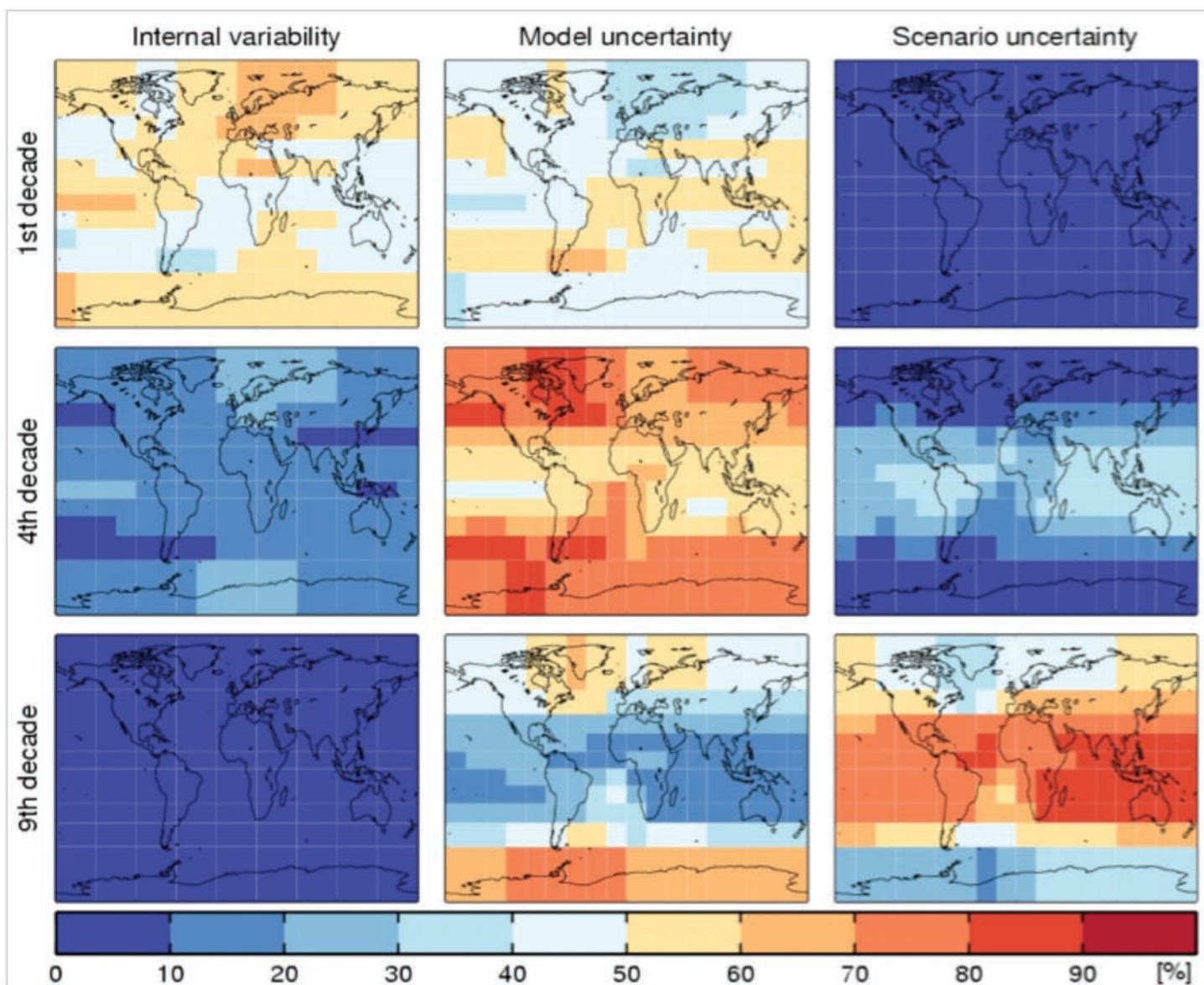


FIGURE A3. Percentage of uncertainty in future temperature projections one decade in the future (top row), four decades in the future (middle row), and nine decades in the future (bottom row) that can be attributed to natural variability (left column), model uncertainty (center column), and scenario uncertainty (right column). Figure from Hawkins & Sutton (endnote reference 124).

APPENDIX B.

CLIMATE GRIDS FOR TWENTY-FIVE STATIONS IN SOUTHERN NEW HAMPSHIRE

This Appendix contains climate grids with historical and projected future thirty-year climatologies for twenty-five Global Historical Climatology Network-Daily (GHCN-Daily) meteorological stations (Table B1) in southern New Hampshire (that is, south of 43.9° north latitude) for the historical period [1980–2009] and the future (near-term [2010–2039], medium-term [2040–2069] and long-term [2070–2099]). The projected values represent the average of daily simulations four Global Climate Models (GCMs) (see Table A1 in the report for more information on the GCMs). Each average was first calculated for each individual GCM, then the results of all four GCMs were averaged.

The climate grids include thirty-year averages of daily measures for minimum and maximum temperature (annual, seasonal, extremes), length of the growing season (number of days between the last hard freeze in the spring and first hard freeze in the fall, using a threshold of 28°F), precipitation (annual, seasonal, extremes), and snow-covered days. There were significant gaps in the daily data from some NH GHCN-Daily stations for the period 1980–2009. Instead, the historical values in these tables were derived from the downscaled GCM model output. The climate grids are arranged in alphabetical order based on the station name.

Station Name	Latitude (N)	Longitude	Elevation (ft)	StationID
Blackwater Dam	43.32	-71.72	183	270741
Deering	43.09	-71.87	325	271950
Durham	43.14	-70.95	23	272174
East Deering	43.07	-71.82	241	272284
Epping	43.03	-71.08	49	272800
Franklin	43.45	-71.67	119	273177
Franklin Falls	43.47	-71.67	131	273182
Grafton	43.57	-71.95	253	273530
Greenland	43.02	-70.83	26	273626
Hanover	43.71	-72.29	178	273850
Hudson	42.78	-71.41	56	274234
Keene	42.94	-72.32	156	274399
Lakeport	43.55	-71.46	152	274480
Lakeport2	43.55	-71.47	171	274475
Manchester	43.03	-71.48	64	275072
Massabesic Lake	42.99	-71.39	77	275211
Mt. Sunapee	43.33	-72.08	387	275629
Nashua	42.77	-71.45	27	275702
Nashua2	42.79	-71.47	41	275712
Newport	43.38	-72.18	235	275868
Peterboro	42.85	-71.95	311	276697
Plymouth	43.78	-71.65	201	276945
Surry Mtn	43.00	-72.31	171	278539
Tamworth	43.90	-71.30	241	278612
Windham	42.82	-71.33	67	279740

TABLE B1. List and location of 25 GHCN-Daily stations in southern New Hampshire for which climate grids are provided.

Blackwater Dam, New Hampshire

Indicators	Historical* 1980–2009	Change from historical (+ or -)					
		Short Term 2010–2039		Medium Term 2040–2069		Long Term 2070–2099	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions

Minimum Temperature (°F)

Annual TMIN	33.6	1.6	1.9	2.7	5.0	3.6	8.4
Winter TMIN	11.2	2.3	2.7	3.6	5.7	4.9	9.4
Spring TMIN	32.2	2.9	1.3	4.5	3.9	5.6	7.0
Summer TMIN	54.3	1.5	2.1	2.7	5.4	3.3	9.1
Fall TMIN	36.1	0.0	1.8	0.3	5.1	0.8	8.4

Maximum Temperature (°F)

Annual TMAX	56.3	1.7	1.7	3.0	4.9	4.0	8.3
Winter TMAX	32.0	1.8	1.7	2.6	3.7	3.7	6.3
Spring TMAX	54.6	2.6	1.5	5.1	4.7	7.0	8.7
Summer TMAX	79.2	1.7	2.1	3.3	5.7	4.1	9.4
Fall TMAX	58.8	0.8	1.9	1.2	5.6	1.4	8.9

Temperature Extreme (days per year)

<32°F	169	-8	-11	-15	-24	-18	-42
<0°F	18	-5	-5	-8	-12	-10	-16
>90°F	5	4	5	10	20	16	45
>95°F	0	1	1	3	5	6	18
TMAX on hottest day of year	92.5	2.2	1.2	3.8	4.3	5.6	8.3
TMIN on coldest day of year	-17.1	3.7	4.4	5.9	10.1	7.8	17.3
Growing Season (days)	162	12	13	17	29	20	47

Precipitation (inches)

Annual mean	44.0	4.5	2.6	5.6	5.9	7.4	8.9
Winter mean	10.3	1.3	0.9	1.5	1.5	2.2	3.2
Spring mean	10.8	1.4	1.1	2.2	1.8	2.2	2.8
Summer mean	11.6	1.8	0.7	1.3	1.8	2.6	1.5
Fall mean	11.3	0.1	0.0	0.5	0.6	0.6	1.4

Extreme Precipitation (events per year)

1" in 24 hrs	11.0	1.8	1.3	2.3	2.8	2.8	4.1
2" in 48 hours	4.9	1.6	0.9	1.7	2.2	2.5	4.2

Extreme Precipitation (events per decade)

4" in 48 hours	4.3	2.3	1.1	4.3	5.4	7.0	8.8
Snow-Covered Days	96	-14	-15	-20	-36	-29	-51

*There were significant gaps in the daily data from some New Hampshire sites for the period 1980–2009. Instead, the historical values in these tables were derived from the downscaled GCM model output.

Deering, New Hampshire

Indicators	Historical* 1980–2009	Change from historical (+ or -)					
		Short Term 2010–2039		Medium Term 2040–2069		Long Term 2070–2099	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions

Minimum Temperature (°F)

Annual TMIN	37.3	1.7	1.9	2.8	4.9	3.6	8.3
Winter TMIN	16.5	2.1	2.3	3.4	5.1	4.6	8.6
Spring TMIN	35.1	2.9	1.5	4.6	4.0	5.7	7.2
Summer TMIN	57.2	1.4	1.9	2.6	5.2	3.2	9.0
Fall TMIN	40.1	0.2	1.8	0.4	5.1	0.9	8.5

Maximum Temperature (°F)

Annual TMAX	56.1	1.6	1.7	2.8	4.6	3.7	7.9
Winter TMAX	32.9	1.8	1.5	2.6	3.5	3.7	6.1
Spring TMAX	55.9	2.4	1.6	4.7	4.5	6.3	8.2
Summer TMAX	77.7	1.4	1.9	2.8	5.1	3.5	8.6
Fall TMAX	57.6	0.8	1.6	1.2	5.2	1.4	8.5

Temperature Extreme (days per year)

<32°F	143	-10	-11	-16	-25	-20	-43
<0°F	8	-3	-4	-5	-6	-6	-8
>90°F	2	1	2	4	12	8	32
>95°F	0	0	0	0	2	2	10
TMAX on hottest day of year	89.5	1.5	1.3	2.8	4.7	4.7	8.4
TMIN on coldest day of year	-9.4	3.3	3.5	5.4	9.0	6.7	15.3
Growing Season (days)	186	13	14	18	30	22	48

Precipitation (inches)

Annual mean	47.7	5.8	3.3	9.1	7.8	11.0	11.6
Winter mean	11.6	1.4	0.9	2.7	2.9	3.5	5.9
Spring mean	12.0	1.6	1.0	2.5	1.0	2.8	2.4
Summer mean	11.2	1.8	0.8	1.4	1.7	2.5	0.9
Fall mean	12.9	1.1	0.6	2.5	2.2	2.2	2.5

Extreme Precipitation (events per year)

1" in 24 hrs	11.6	2.2	1.5	2.9	2.2	3.8	3.5
2" in 48 hours	5.6	2.2	1.3	2.8	2.4	3.7	4.3

Extreme Precipitation (events per decade)

4" in 48 hours	7.8	5.4	0.7	9.8	6.1	10.7	12.6
Snow-Covered Days	81	-13	-13	-17	-33	-25	-44

*There were significant gaps in the daily data from some New Hampshire sites for the period 1980–2009. Instead, the historical values in these tables were derived from the downscaled GCM model output.

Durham, New Hampshire

Indicators	Historical* 1980–2009	Change from historical (+ or -)					
		Short Term 2010–2039		Medium Term 2040–2069		Long Term 2070–2099	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions

Minimum Temperature (°F)

Annual TMIN	35.9	1.8	2.0	3.0	5.3	3.9	9.2
Winter TMIN	15.6	2.3	2.6	3.6	5.6	4.9	9.3
Spring TMIN	33.4	2.9	1.6	4.6	4.3	5.9	7.7
Summer TMIN	55.5	1.7	2.3	3.1	6.1	3.8	10.8
Fall TMIN	38.7	0.3	1.8	0.7	5.4	1.2	9.0

Maximum Temperature (°F)

Annual TMAX	59.3	1.7	1.7	3.0	4.9	4.0	8.3
Winter TMAX	36.2	1.7	1.5	2.4	3.4	3.5	6.0
Spring TMAX	57.4	2.5	1.6	4.8	4.8	6.6	8.8
Summer TMAX	81.2	1.8	2.2	3.4	5.9	4.3	9.8
Fall TMAX	62.0	0.9	1.7	1.3	5.3	1.6	8.5

Temperature Extreme (days per year)

<32°F	154	-11	-11	-18	-28	-22	-48
<0°F	10	-3	-4	-6	-7	-6	-10
>90°F	10	6	7	15	28	21	57
>95°F	2	1	1	4	11	8	32
TMAX on hottest day of year	94.8	1.8	1.4	3.0	4.5	5.0	7.9
TMIN on coldest day of year	-13.5	4.1	5.0	6.6	11.0	8.5	18.6
Growing Season (days)	164	14	15	20	31	24	54

Precipitation (inches)

Annual mean	43.7	4.2	3.8	5.2	6.8	7.1	10.4
Winter mean	9.6	1.1	0.8	1.4	1.3	2.1	2.8
Spring mean	11.2	1.2	2.0	1.4	2.4	2.1	3.9
Summer mean	10.6	1.4	0.8	1.3	2.2	2.1	2.5
Fall mean	12.4	0.5	0.1	1.0	0.8	0.8	1.2

Extreme Precipitation (events per year)

1" in 24 hrs	10.8	1.2	2.0	1.8	3.3	2.2	4.6
2" in 48 hours	5.1	1.3	1.4	1.8	2.6	2.7	4.4

Extreme Precipitation (events per decade)

4" in 48 hours	6.6	3.2	0.2	4.8	5.4	7.4	10.3
Snow-Covered Days	77	-15	-16	-20	-34	-27	-45

*There were significant gaps in the daily data from some New Hampshire sites for the period 1980–2009. Instead, the historical values in these tables were derived from the downscaled GCM model output.

East Deering, New Hampshire

Indicators	Historical* 1980–2009	Change from historical (+ or -)					
		Short Term 2010–2039		Medium Term 2040–2069		Long Term 2070–2099	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions

Minimum Temperature (°F)

Annual TMIN	33.4	1.8	2.2	2.9	5.4	3.9	9.1
Winter TMIN	12.1	2.2	2.7	3.6	5.7	4.9	9.4
Spring TMIN	31.1	3.3	1.4	5.0	4.2	6.2	7.6
Summer TMIN	53.7	1.6	2.3	2.8	5.8	3.5	10.0
Fall TMIN	36.5	-0.1	2.1	0.2	5.6	0.7	9.1

Maximum Temperature (°F)

Annual TMAX	56.2	1.6	1.7	2.9	4.7	3.8	8.1
Winter TMAX	32.8	1.6	1.6	2.3	3.4	3.4	5.8
Spring TMAX	54.3	2.6	1.4	5.0	4.5	6.7	8.3
Summer TMAX	78.3	1.7	1.9	3.1	5.3	3.9	9.1
Fall TMAX	59.1	0.7	2.0	1.1	5.5	1.3	8.7

Temperature Extreme (days per year)

<32°F	174	-8	-12	-15	-26	-18	-44
<0°F	17	-5	-5	-8	-12	-10	-16
>90°F	3	3	2	7	13	12	35
>95°F	0	1	1	2	3	4	14
TMAX on hottest day of year	91.4	2.1	1.7	3.4	5.8	5.5	10.4
TMIN on coldest day of year	-17.9	4.2	5.1	6.6	11.1	8.4	18.6
Growing Season (days)	150	8	12	16	30	19	53

Precipitation (inches)

Annual mean	44.9	4.2	3.1	5.0	5.5	6.9	8.4
Winter mean	10.5	1.2	1.1	1.3	1.4	1.9	3.1
Spring mean	10.8	1.1	0.9	1.9	1.6	2.0	2.9
Summer mean	11.5	1.6	1.2	0.9	2.3	2.0	1.9
Fall mean	12.0	0.5	0.1	1.0	0.1	1.0	0.6

Extreme Precipitation (events per year)

1" in 24 hrs	10.9	1.8	1.6	2.0	2.6	2.7	4.2
2" in 48 hours	4.8	2.0	1.3	2.2	2.1	2.9	4.2

Extreme Precipitation (events per decade)

4" in 48 hours	5.5	2.1	-0.9	4.0	3.8	6.5	6.0
Snow-Covered Days	81	-13	-13	-17	-33	-25	-44

*There were significant gaps in the daily data from some New Hampshire sites for the period 1980–2009. Instead, the historical values in these tables were derived from the downscaled GCM model output.

Epping, New Hampshire

Indicators	Historical* 1980–2009	Change from historical (+ or -)					
		Short Term 2010–2039		Medium Term 2040–2069		Long Term 2070–2099	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions

Minimum Temperature (°F)

Annual TMIN	35.9	1.8	2.1	3.0	5.3	3.9	9.2
Winter TMIN	15.7	2.3	2.5	3.6	5.4	4.9	9.1
Spring TMIN	33.6	2.9	1.6	4.6	4.3	5.8	7.6
Summer TMIN	55.8	1.7	2.2	3.0	6.0	3.7	11.0
Fall TMIN	38.3	0.4	1.8	0.7	5.3	1.2	8.9

Maximum Temperature (°F)

Annual TMAX	58.6	1.7	1.7	3.0	4.9	4.0	8.3
Winter TMAX	35.5	1.7	1.6	2.5	3.6	3.7	6.3
Spring TMAX	56.7	2.6	1.7	5.0	4.9	6.7	9.0
Summer TMAX	80.5	1.8	2.2	3.4	5.8	4.2	9.5
Fall TMAX	61.1	1.0	1.7	1.4	5.3	1.6	8.6

Temperature Extreme (days per year)

<32°F	157	-11	-12	-17	-28	-22	-48
<0°F	10	-4	-4	-6	-7	-7	-9
>90°F	8	5	6	13	25	18	54
>95°F	1	1	1	2	8	4	24
TMAX on hottest day of year	93.5	1.5	1.4	2.4	4.2	3.7	7.7
TMIN on coldest day of year	-12.9	4.0	4.5	6.5	10.5	8.3	17.9
Growing Season (days)	164	13	12	20	30	21	52

Precipitation (inches)

Annual mean	45.7	4.7	2.8	6.4	6.0	8.7	9.2
Winter mean	10.6	1.2	0.9	1.5	1.2	2.4	2.9
Spring mean	12.1	1.3	1.3	2.1	1.9	2.8	3.7
Summer mean	10.7	1.9	0.4	1.6	1.3	2.5	0.7
Fall mean	12.3	0.4	0.3	1.2	1.4	1.0	2.0

Extreme Precipitation (events per year)

1" in 24 hrs	11.1	1.7	1.6	2.4	2.9	3.1	4.2
2" in 48 hours	5.2	1.6	1.4	2.4	2.4	3.1	4.5

Extreme Precipitation (events per decade)

4" in 48 hours	5.6	3.7	-0.4	6.9	6.4	8.3	11.8
Snow-Covered Days	77	-15	-17	-20	-34	-26	-44

*There were significant gaps in the daily data from some New Hampshire sites for the period 1980–2009. Instead, the historical values in these tables were derived from the downscaled GCM model output.

Franklin, New Hampshire

Indicators	Historical* 1980–2009	Change from historical (+ or -)					
		Short Term 2010–2039		Medium Term 2040–2069		Long Term 2070–2099	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions

Minimum Temperature (°F)

Annual TMIN	34.2	1.7	2.1	2.9	5.2	3.8	8.8
Winter TMIN	11.5	2.3	2.8	3.7	5.9	5.1	9.7
Spring TMIN	31.7	3.2	1.3	4.9	4.1	6.2	7.5
Summer TMIN	54.9	1.5	2.1	2.7	5.5	3.3	9.4
Fall TMIN	38.4	-0.1	2.1	0.2	5.4	0.7	8.7

Maximum Temperature (°F)

Annual TMAX	58.8	1.7	1.7	2.9	4.7	3.9	8.1
Winter TMAX	32.9	1.6	1.6	2.2	3.3	3.2	5.6
Spring TMAX	57.5	2.7	1.3	5.2	4.4	7.0	8.3
Summer TMAX	82.6	1.7	1.9	3.1	5.4	3.9	9.2
Fall TMAX	61.9	0.7	2.0	1.1	5.7	1.4	9.0

Temperature Extreme (days per year)

<32°F	164	-9	-11	-15	-25	-18	-43
<0°F	18	-5	-5	-9	-12	-10	-16
>90°F	14	7	7	17	29	24	57
>95°F	2	3	2	7	12	12	32
TMAX on hottest day of year	95.8	2.2	1.4	3.2	5.4	5.6	9.8
TMIN on coldest day of year	-20.2	5.0	5.8	7.4	12.6	9.9	20.6
Growing Season (days)	160	12	15	17	31	19	52

Precipitation (inches)

Annual mean	38.5	3.4	1.7	3.7	3.5	5.4	5.1
Winter mean	8.6	0.9	0.9	1.1	1.2	1.6	2.6
Spring mean	9.6	0.5	0.4	0.7	0.6	1.1	1.2
Summer mean	9.5	1.5	0.2	1.1	0.8	1.8	-0.1
Fall mean	10.9	0.4	0.2	0.8	0.7	0.8	1.2

Extreme Precipitation (events per year)

1" in 24 hrs	7.7	1.7	1.2	1.8	2.0	2.3	3.2
2" in 48 hours	3.3	1.1	0.6	1.4	1.4	1.9	2.9

Extreme Precipitation (events per decade)

4" in 48 hours	3.3	1.3	-0.2	1.1	2.5	3.1	3.6
Snow-Covered Days	105	-14	-14	-20	-37	-30	-54

*There were significant gaps in the daily data from some New Hampshire sites for the period 1980–2009. Instead, the historical values in these tables were derived from the downscaled GCM model output.

Franklin Falls, New Hampshire

Indicators	Historical* 1980–2009	Change from historical (+ or -)					
		Short Term 2010–2039		Medium Term 2040–2069		Long Term 2070–2099	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions

Minimum Temperature (°F)

Annual TMIN	32.3	1.8	2.1	2.9	5.3	3.8	8.9
Winter TMIN	9.6	2.3	2.8	3.7	5.9	5.0	9.8
Spring TMIN	31.0	2.9	1.5	4.6	4.3	5.8	7.5
Summer TMIN	53.7	1.5	2.2	2.7	5.7	3.4	9.7
Fall TMIN	34.6	0.2	1.8	0.5	5.1	1.0	8.5

Maximum Temperature (°F)

Annual TMAX	57.1	1.8	1.9	3.1	5.1	4.1	8.6
Winter TMAX	33.2	1.8	1.8	2.6	3.7	3.7	6.4
Spring TMAX	55.8	2.6	1.7	5.0	4.9	6.7	8.9
Summer TMAX	79.9	1.8	2.3	3.5	6.2	4.3	10.3
Fall TMAX	59.1	0.9	1.8	1.3	5.4	1.5	8.7

Temperature Extreme (days per year)

<32°F	178	-9	-11	-15	-25	-18	-43
<0°F	23	-6	-6	-10	-14	-11	-19
>90°F	8	5	6	12	24	17	50
>95°F	1	1	2	3	10	6	27
TMAX on hottest day of year	94.2	1.9	1.8	3.1	5.8	5.1	10.6
TMIN on coldest day of year	-18.6	3.6	3.7	5.6	9.3	7.3	16.6
Growing Season (days)	148	9	10	17	28	20	50

Precipitation (inches)

Annual mean	43.0	4.4	2.6	5.6	6.4	8.6	9.8
Winter mean	9.7	1.2	1.0	1.2	1.4	2.1	3.0
Spring mean	10.4	1.3	0.9	2.1	1.6	2.4	2.8
Summer mean	11.6	1.6	1.1	1.1	2.6	2.3	2.3
Fall mean	11.2	0.5	-0.3	1.2	0.8	1.8	1.7

Extreme Precipitation (events per year)

1" in 24 hrs	9.7	1.9	1.5	2.6	2.9	3.2	4.6
2" in 48 hours	4.2	1.4	0.9	1.8	2.3	2.7	4.3

Extreme Precipitation (events per decade)

4" in 48 hours	3.9	2.8	-1.1	2.4	3.9	6.4	7.1
Snow-Covered Days	105	-14	-14	-20	-37	-30	-54

*There were significant gaps in the daily data from some New Hampshire sites for the period 1980–2009. Instead, the historical values in these tables were derived from the downscaled GCM model output.

Grafton, New Hampshire

Indicators	Historical* 1980–2009	Change from historical (+ or -)					
		Short Term 2010–2039		Medium Term 2040–2069		Long Term 2070–2099	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions

Minimum Temperature (°F)

Annual TMIN	30.4	2.0	2.3	3.3	5.7	4.3	9.7
Winter TMIN	8.2	2.7	3.1	4.3	6.5	5.9	10.9
Spring TMIN	28.5	3.3	1.6	5.2	4.7	6.4	8.2
Summer TMIN	50.9	1.8	2.4	3.2	6.2	3.9	10.6
Fall TMIN	33.7	0.2	1.9	0.5	5.4	1.0	9.0

Maximum Temperature (°F)

Annual TMAX	55.4	1.7	1.7	3.0	4.8	4.0	8.3
Winter TMAX	31.0	1.9	1.7	2.7	3.7	3.9	6.4
Spring TMAX	54.1	2.5	1.6	4.9	4.8	6.6	8.7
Summer TMAX	78.2	1.7	2.1	3.3	5.7	4.1	9.4
Fall TMAX	57.7	0.9	1.7	1.3	5.4	1.5	8.7

Temperature Extreme (days per year)

<32°F	189	-10	-12	-18	-28	-21	-48
<0°F	29	-8	-7	-11	-16	-14	-24
>90°F	4	2	3	8	16	13	40
>95°F	0	1	1	2	4	4	15
TMAX on hottest day of year	91.6	1.9	1.4	3.0	4.4	4.1	7.4
TMIN on coldest day of year	-24.6	4.6	5.0	7.1	11.6	9.2	20.2
Growing Season (days)	128	8	11	17	31	21	53

Precipitation (inches)

Annual mean	39.2	3.5	3.2	4.2	5.6	6.2	8.3
Winter mean	8.3	1.2	0.8	1.1	1.2	1.7	2.4
Spring mean	9.7	0.5	1.0	1.3	1.3	1.7	2.5
Summer mean	10.8	1.5	1.0	0.8	2.4	2.0	2.1
Fall mean	10.4	0.4	0.4	0.9	0.6	0.9	1.4

Extreme Precipitation (events per year)

1" in 24 hrs	8.8	1.3	1.8	1.9	2.7	2.2	4.4
2" in 48 hours	3.4	1.1	1.1	1.2	2.0	1.9	3.6

Extreme Precipitation (events per decade)

4" in 48 hours	2.2	2.9	1.0	1.4	2.9	4.8	5.7
Snow-Covered Days	112	-13	-13	-19	-36	-28	-53

*There were significant gaps in the daily data from some New Hampshire sites for the period 1980–2009. Instead, the historical values in these tables were derived from the downscaled GCM model output.

Greenland, New Hampshire

Indicators	Historical* 1980–2009	Change from historical (+ or -)					
		Short Term 2010–2039		Medium Term 2040–2069		Long Term 2070–2099	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions

Minimum Temperature (°F)

Annual TMIN	37.5	1.8	2.0	3.0	5.2	3.9	8.9
Winter TMIN	18.1	2.2	2.3	3.4	5.1	4.6	8.7
Spring TMIN	34.9	2.8	1.6	4.4	4.3	5.6	7.5
Summer TMIN	56.4	1.8	2.3	3.1	6.0	3.8	10.5
Fall TMIN	40.3	0.5	1.6	0.8	5.2	1.3	8.7

Maximum Temperature (°F)

Annual TMAX	59.0	1.7	1.7	3.1	5.0	4.1	8.7
Winter TMAX	37.0	1.8	1.5	2.6	3.5	3.7	6.2
Spring TMAX	56.6	2.5	1.7	4.9	5.0	6.7	9.2
Summer TMAX	80.2	1.9	2.4	3.6	6.4	4.6	10.7
Fall TMAX	61.6	1.0	1.5	1.4	5.2	1.7	8.6

Temperature Extreme (days per year)

<32°F	142	-12	-12	-18	-29	-24	-50
<0°F	6	-3	-3	-4	-5	-5	-6
>90°F	9	5	7	14	28	19	57
>95°F	1	2	2	4	12	8	33
TMAX on hottest day of year	94.7	1.7	1.8	3.1	5.6	5.0	10.8
TMIN on coldest day of year	-8.8	3.7	4.4	5.9	9.8	7.7	16.7
Growing Season (days)	177	14	14	22	33	28	54

Precipitation (inches)

Annual mean	49.7	4.7	3.9	6.5	8.3	8.0	12.0
Winter mean	11.9	1.4	1.2	1.8	1.9	2.4	3.7
Spring mean	13.4	1.0	1.0	1.5	2.0	2.2	3.3
Summer mean	11.0	1.4	1.1	1.3	2.2	2.1	2.6
Fall mean							

Extreme Precipitation (events per year)

1" in 24 hrs	13.5	1.6	1.6	2.5	3.1	3.1	4.5
2" in 48 hours	7.1	1.6	1.7	2.6	3.8	3.1	5.8

Extreme Precipitation (events per decade)

4" in 48 hours	9.6	2.8	0.5	5.9	9.3	7.6	17.5
Snow-Covered Days	92	-13	-12	-18	-30	-27	-45

*There were significant gaps in the daily data from some New Hampshire sites for the period 1980–2009. Instead, the historical values in these tables were derived from the downscaled GCM model output.

Hanover, New Hampshire

Indicators	Historical* 1980–2009	Change from historical (+ or -)					
		Short Term 2010–2039		Medium Term 2040–2069		Long Term 2070–2099	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions

Minimum Temperature (°F)

Annual TMIN	35.2	1.8	2.0	2.9	5.1	3.9	8.8
Winter TMIN	12.3	2.5	2.9	4.0	6.2	5.5	10.3
Spring TMIN	32.9	3.0	1.6	4.7	4.4	5.9	7.7
Summer TMIN	56.2	1.5	2.0	2.6	5.2	3.2	9.0
Fall TMIN	38.9	0.2	1.6	0.5	4.9	1.0	8.1

Maximum Temperature (°F)

Annual TMAX	56.7	1.8	1.8	3.1	4.9	4.0	8.3
Winter TMAX	31.5	1.8	1.7	2.7	3.6	3.9	6.3
Spring TMAX	56.0	2.5	1.6	4.9	4.8	6.6	8.7
Summer TMAX	80.3	1.8	2.1	3.3	5.8	4.2	9.6
Fall TMAX	58.7	0.9	1.6	1.3	5.3	1.5	8.5

Temperature Extreme (days per year)

<32°F	156	-10	-10	-16	-26	-20	-44
<0°F	18	-5	-5	-9	-12	-10	-16
>90°F	8	5	6	13	24	18	50
>95°F	1	1	2	4	10	6	27
TMAX on hottest day of year	94.2	1.8	1.3	2.9	4.6	4.0	8.3
TMIN on coldest day of year	-18.0	4.0	4.4	6.1	10.7	8.1	18.6
Growing Season (days)	168	14	14	20	31	23	51

Precipitation (inches)

Annual mean	38.5	3.7	2.9	4.5	6.2	6.4	9.1
Winter mean	8.2	0.9	0.6	0.9	1.1	1.5	2.2
Spring mean	9.3	0.8	1.0	1.6	1.7	1.7	3.0
Summer mean	10.7	1.4	0.7	0.9	1.9	2.1	1.4
Fall mean							

Extreme Precipitation (events per year)

1" in 24 hrs	8.2	1.6	1.6	2.1	2.8	3.0	4.9
2" in 48 hours	3.1	1.2	0.8	1.1	2.2	2.2	3.5

Extreme Precipitation (events per decade)

4" in 48 hours	1.0	1.6	0.7	1.4	2.7	4.3	4.9
Snow-Covered Days	117	-10	-11	-17	-33	-25	-50

*There were significant gaps in the daily data from some New Hampshire sites for the period 1980–2009. Instead, the historical values in these tables were derived from the downscaled GCM model output.

Hudson, New Hampshire

Indicators	Historical* 1980–2009	Change from historical (+ or -)					
		Short Term 2010–2039		Medium Term 2040–2069		Long Term 2070–2099	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions

Minimum Temperature (°F)

Annual TMIN	35.3	1.8	1.9	3.0	5.1	3.9	8.8
Winter TMIN	14.0	2.3	2.3	3.6	5.1	4.8	8.7
Spring TMIN	32.8	2.8	1.7	4.5	4.5	5.7	7.8
Summer TMIN	56.4	1.7	2.2	2.9	5.7	3.6	9.8
Fall TMIN	37.7	0.6	1.5	0.9	5.0	1.3	8.7

Maximum Temperature (°F)

Annual TMAX	58.8	1.8	1.7	3.2	5.0	4.1	8.5
Winter TMAX	36.1	1.9	1.5	2.7	3.5	3.8	6.1
Spring TMAX	56.7	2.6	1.8	5.1	5.1	6.8	9.3
Summer TMAX	80.6	1.8	2.3	3.5	6.2	4.4	10.3
Fall TMAX	61.3	1.1	1.4	1.5	5.1	1.6	8.3

Temperature Extreme (days per year)

<32°F	163	-11	-10	-17	-25	-21	-43
<0°F	12	-5	-4	-7	-8	-8	-11
>90°F	11	5	7	14	27	20	56
>95°F	2	1	2	4	13	6	33
TMAX on hottest day of year	95.0	1.5	1.6	2.6	5.2	4.1	9.5
TMIN on coldest day of year	-12.9	3.6	3.7	5.9	9.1	7.6	15.8
Growing Season (days)	163	12	11	16	26	20	45

Precipitation (inches)

Annual mean	45.8	2.8	4.2	3.9	5.9	6.0	7.9
Winter mean	10.4	1.1	0.7	1.3	1.1	1.9	2.5
Spring mean	12.3	0.9	1.5	1.1	1.9	2.1	2.2
Summer mean	10.3	0.6	1.4	0.6	2.2	1.2	2.0
Fall mean							

Extreme Precipitation (events per year)

1" in 24 hrs	11.2	1.1	2.0	1.4	2.8	2.0	3.3
2" in 48 hours	5.3	1.1	1.5	1.4	2.3	2.5	3.8

Extreme Precipitation (events per decade)

4" in 48 hours	7.7	2.6	1.8	4.3	3.5	7.7	7.0
Snow-Covered Days	77	-14	-15	-19	-34	-27	-45

*There were significant gaps in the daily data from some New Hampshire sites for the period 1980–2009. Instead, the historical values in these tables were derived from the downscaled GCM model output.

Keene, New Hampshire

Indicators	Historical* 1980–2009	Change from historical (+ or -)					
		Short Term 2010–2039		Medium Term 2040–2069		Long Term 2070–2099	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions

Minimum Temperature (°F)

Annual TMIN	34.8	1.8	2.1	3.0	5.3	4.0	9.1
Winter TMIN	13.5	2.4	2.7	3.8	5.9	5.3	9.8
Spring TMIN	32.4	3.1	1.7	4.9	4.5	6.1	7.9
Summer TMIN	55.1	1.6	2.2	2.9	5.8	3.5	9.9
Fall TMIN	37.7	0.3	1.8	0.6	5.3	1.1	8.8

Maximum Temperature (°F)

Annual TMAX	58.8	1.6	1.7	2.9	4.7	3.8	7.9
Winter TMAX	34.5	1.7	1.6	2.5	3.4	3.6	5.9
Spring TMAX	57.6	2.6	1.6	5.0	4.8	6.6	8.6
Summer TMAX	81.4	1.6	1.9	3.0	5.3	3.8	8.7
Fall TMAX	61.2	0.9	1.7	1.3	5.2	1.5	8.4

Temperature Extreme (days per year)

<32°F	163	-10	-13	-17	-28	-22	-48
<0°F	16	-5	-5	-8	-11	-9	-15
>90°F	9	5	6	13	26	19	53
>95°F	1	1	2	3	9	6	26
TMAX on hottest day of year	94.0	1.3	1.1	2.2	4.1	3.1	7.3
TMIN on coldest day of year	-17.1	3.9	4.5	6.4	10.7	8.5	18.4
Growing Season (days)	156	12	12	18	29	19	51

Precipitation (inches)

Annual mean	41.6	4.6	3.4	5.4	6.4	6.9	9.2
Winter mean	9.0	0.9	0.7	1.0	1.0	1.6	2.3
Spring mean	10.1	1.4	1.1	1.9	1.8	2.1	2.6
Summer mean	11.4	1.7	1.5	1.3	2.4	2.1	2.1
Fall mean							

Extreme Precipitation (events per year)

1" in 24 hrs	9.2	2.3	1.6	2.5	3.2	3.1	4.4
2" in 48 hours	3.4	1.3	0.9	1.8	1.9	1.9	3.6

Extreme Precipitation (events per decade)

4" in 48 hours	1.5	2.2	0.4	3.2	2.8	5.0	6.0
Snow-Covered Days	94	-11	-11	-17	-33	-24	-46

*There were significant gaps in the daily data from some New Hampshire sites for the period 1980–2009. Instead, the historical values in these tables were derived from the downscaled GCM model output.

Lakeport (1), New Hampshire

Indicators	Historical* 1980–2009	Change from historical (+ or -)					
		Short Term 2010–2039		Medium Term 2040–2069		Long Term 2070–2099	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions

Minimum Temperature (°F)

Annual TMIN	36.4	1.6	1.9	2.6	4.7	3.5	8.1
Winter TMIN	13.5	2.1	2.5	3.3	5.4	4.6	8.9
Spring TMIN	33.4	3.0	1.3	4.5	3.9	5.7	7.0
Summer TMIN	57.8	1.4	1.9	2.5	4.9	3.0	8.5
Fall TMIN	40.4	0.0	1.8	0.3	4.8	0.8	7.9

Maximum Temperature (°F)

Annual TMAX	55.4	1.7	1.7	3.0	4.9	3.9	8.3
Winter TMAX	30.4	1.7	1.6	2.5	3.6	3.6	6.1
Spring TMAX	54.4	2.7	1.5	5.2	4.7	6.8	8.7
Summer TMAX	79.0	1.8	2.0	3.3	5.6	4.1	9.3
Fall TMAX	57.3	0.8	1.9	1.2	5.7	1.4	9.1

Temperature Extreme (days per year)

<32°F	152	-9	-10	-15	-23	-18	-38
<0°F	12	-4	-4	-6	-9	-7	-11
>90°F	5	3	4	9	18	15	43
>95°F	0	1	1	2	4	3	16
TMAX on hottest day of year	92.2	1.8	1.1	3.0	4.7	4.3	9.0
TMIN on coldest day of year	-13.2	3.6	4.2	5.6	9.6	7.4	16.5
Growing Season (days)	188	10	11	14	26	21	40

Precipitation (inches)

Annual mean	41.5	3.8	2.5	4.8	5.5	6.8	8.5
Winter mean	9.6	0.9	0.7	1.0	1.1	1.8	2.6
Spring mean	9.9	1.1	0.8	1.8	1.7	1.8	3.0
Summer mean	11.3	1.3	1.0	0.8	2.1	1.9	1.9
Fall mean							

Extreme Precipitation (events per year)

1" in 24 hrs	9.1	1.5	1.2	2.0	2.5	2.7	4.1
2" in 48 hours	3.7	1.4	0.8	1.7	1.8	2.4	3.8

Extreme Precipitation (events per decade)

4" in 48 hours	3.9	1.5	0.3	2.4	2.8	4.1	4.9
Snow-Covered Days	112	-14	-16	-21	-39	-32	-58

*There were significant gaps in the daily data from some New Hampshire sites for the period 1980–2009. Instead, the historical values in these tables were derived from the downscaled GCM model output.

Lakeport (2), New Hampshire

Indicators	Historical* 1980–2009	Change from historical (+ or -)					
		Short Term 2010–2039		Medium Term 2040–2069		Long Term 2070–2099	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions

Minimum Temperature (°F)

Annual TMIN	36.7	1.7	1.8	2.7	4.6	3.6	8.0
Winter TMIN	14.8	2.1	2.2	3.4	5.0	4.6	8.4
Spring TMIN	33.4	2.7	1.6	4.2	4.2	5.4	7.2
Summer TMIN	57.8	1.4	1.8	2.5	4.9	3.1	8.9
Fall TMIN	40.5	0.4	1.2	0.7	4.2	1.1	7.1

Maximum Temperature (°F)

Annual TMAX	56.9	1.8	1.8	3.1	4.9	4.1	8.4
Winter TMAX	32.9	1.9	1.6	2.7	3.5	3.8	6.1
Spring TMAX	55.0	2.5	1.8	4.9	5.0	6.5	9.0
Summer TMAX	79.6	1.8	2.2	3.5	6.1	4.3	10.1
Fall TMAX	59.7	1.0	1.4	1.4	5.0	1.6	8.2

Temperature Extreme (days per year)

<32°F	148	-10	-10	-16	-23	-19	-40
<0°F	10	-4	-4	-6	-7	-7	-9
>90°F	7	5	6	12	24	17	50
>95°F	1	1	2	3	10	4	27
TMAX on hottest day of year	93.8	1.5	1.8	2.5	5.5	3.6	10.2
TMIN on coldest day of year	-11.2	3.7	3.8	5.6	8.9	7.6	15.5
Growing Season (days)	191	12	12	15	27	23	43

Precipitation (inches)

Annual mean	40.7	4.3	2.7	5.5	5.0	7.2	7.4
Winter mean	8.5	0.9	0.6	1.1	1.0	1.5	1.9
Spring mean	9.8	1.1	1.1	1.9	1.8	2.1	2.9
Summer mean	11.3	1.9	0.7	1.2	1.9	2.4	1.5
Fall mean							

Extreme Precipitation (events per year)

1" in 24 hrs	9.2	1.7	1.4	2.3	2.5	3.0	4.1
2" in 48 hours	3.7	1.3	0.7	1.7	1.7	2.5	3.4

Extreme Precipitation (events per decade)

4" in 48 hours	3.2	2.6	-0.4	4.1	1.8	4.6	4.4
Snow-Covered Days	112	-14	-16	-21	-39	-32	-58

*There were significant gaps in the daily data from some New Hampshire sites for the period 1980–2009. Instead, the historical values in these tables were derived from the downscaled GCM model output.

Manchester, New Hampshire

Indicators	Historical* 1980–2009	Change from historical (+ or -)					
		Short Term 2010–2039		Medium Term 2040–2069		Long Term 2070–2099	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions

Minimum Temperature (°F)

Annual TMIN	34.5	1.5	1.9	2.6	4.9	3.5	8.3
Winter TMIN	11.8	2.2	2.6	3.4	5.5	4.7	9.0
Spring TMIN	32.1	2.9	1.2	4.4	3.7	5.6	6.7
Summer TMIN	55.1	1.4	2.0	2.5	5.2	3.1	9.0
Fall TMIN	38.4	0.0	1.9	0.3	5.2	0.7	8.5

Maximum Temperature (°F)

Annual TMAX	58.8	1.7	1.8	3.1	5.0	4.1	8.5
Winter TMAX	33.7	1.6	1.6	2.3	3.5	3.4	5.9
Spring TMAX	56.5	2.9	1.5	5.5	4.8	7.4	8.9
Summer TMAX	81.9	1.8	2.1	3.5	5.9	4.4	9.9
Fall TMAX	62.5	0.8	2.1	1.2	5.9	1.4	9.5

Temperature Extreme (days per year)

<32°F	160	-8	-10	-13	-22	-16	-38
<0°F	15	-4	-5	-7	-10	-9	-14
>90°F	14	7	7	18	30	24	59
>95°F	3	2	2	7	13	12	36
TMAX on hottest day of year	96.4	2.8	1.4	5.1	5.5	7.2	10.0
TMIN on coldest day of year	-16.2	4.0	4.8	6.2	10.6	8.3	17.5
Growing Season (days)	175	11	13	16	27	16	43

Precipitation (inches)

Annual mean	38.4	4.1	3.2	4.6	5.3	6.4	7.5
Winter mean	8.6	1.2	0.9	1.6	1.4	2.0	3.1
Spring mean	9.4	0.8	1.1	0.8	1.4	1.0	2.0
Summer mean	10.4	1.8	0.7	1.5	1.6	2.5	1.0
Fall mean	9.9	0.5	0.6	0.8	0.9	1.0	1.5

Extreme Precipitation (events per year)

1" in 24 hrs	8.3	1.9	1.4	2.3	2.6	2.6	4.3
2" in 48 hours	3.4	1.2	0.9	1.5	1.7	1.9	2.6

Extreme Precipitation (events per decade)

4" in 48 hours	1.8	3.0	1.0	2.9	2.5	5.9	5.9
Snow-Covered Days	91	-14	-14	-19	-36	-29	-49

*There were significant gaps in the daily data from some New Hampshire sites for the period 1980–2009. Instead, the historical values in these tables were derived from the downscaled GCM model output.

Massabesic Lake, New Hampshire

Indicators	Historical* 1980–2009	Change from historical (+ or -)					
		Short Term 2010–2039		Medium Term 2040–2069		Long Term 2070–2099	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions

Minimum Temperature (°F)

Annual TMIN	35.4	1.7	2.0	2.9	5.1	3.8	8.8
Winter TMIN	13.5	2.2	2.5	3.5	5.3	4.7	8.8
Spring TMIN	33.1	2.9	1.6	4.6	4.3	5.8	7.5
Summer TMIN	56.1	1.7	2.2	2.9	5.8	3.6	10.0
Fall TMIN	38.4	0.3	1.8	0.6	5.2	1.1	8.6

Maximum Temperature (°F)

Annual TMAX	58.4	1.7	1.7	3.1	4.9	4.0	8.4
Winter TMAX	35.2	1.7	1.6	2.5	3.5	3.6	6.1
Spring TMAX	56.3	2.6	1.7	5.0	4.9	6.8	8.9
Summer TMAX	80.3	1.8	2.1	3.4	5.8	4.3	9.9
Fall TMAX	61.4	1.0	1.6	1.3	5.2	1.5	8.4

Temperature Extreme (days per year)

<32°F	158	-9	-10	-15	-24	-19	-42
<0°F	13	-5	-5	-7	-9	-8	-12
>90°F	8	5	7	13	26	19	53
>95°F	1	1	2	4	9	7	27
TMAX on hottest day of year	94.2	1.9	1.3	3.3	4.8	5.3	10.8
TMIN on coldest day of year	-14.2	4.1	4.4	6.4	10.1	8.2	17.0
Growing Season (days)	164	14	14	19	30	22	50

Precipitation (inches)

Annual mean	41.3	3.6	3.2	4.8	5.7	7.0	8.8
Winter mean	8.7	0.9	0.9	1.1	1.1	1.6	2.7
Spring mean	10.2	0.9	1.1	1.4	1.6	1.9	3.0
Summer mean	11.0	1.7	1.1	1.3	2.0	2.5	1.9
Fall mean	11.3	0.3	0.2	1.0	1.0	1.1	1.4

Extreme Precipitation (events per year)

1" in 24 hrs	9.3	1.2	1.6	1.7	2.6	2.5	4.4
2" in 48 hours	3.9	1.1	1.2	1.4	1.9	2.0	3.9

Extreme Precipitation (events per decade)

4" in 48 hours	5.1	0.7	-1.3	2.7	3.2	4.1	5.3
Snow-Covered Days	85	-14	-15	-18	-34	-27	-47

*There were significant gaps in the daily data from some New Hampshire sites for the period 1980–2009. Instead, the historical values in these tables were derived from the downscaled GCM model output.

Mount Sunapee, New Hampshire

Indicators	Historical* 1980–2009	Change from historical (+ or -)					
		Short Term 2010–2039		Medium Term 2040–2069		Long Term 2070–2099	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions

Minimum Temperature (°F)

Annual TMIN	35.8	1.7	2.0	2.8	5.1	3.7	8.8
Winter TMIN	14.6	2.2	2.5	3.5	5.4	4.7	8.9
Spring TMIN	33.1	2.8	1.5	4.5	4.2	5.7	7.5
Summer TMIN	56.1	1.6	2.1	2.8	5.7	3.5	10.3
Fall TMIN	39.0	0.3	1.7	0.6	5.0	1.1	8.3

Maximum Temperature (°F)

Annual TMAX	55.1	1.6	1.6	2.9	4.6	3.8	7.8
Winter TMAX	31.4	1.8	1.7	2.6	3.6	3.8	6.3
Spring TMAX	53.7	2.4	1.5	4.7	4.6	6.3	8.4
Summer TMAX	77.2	1.6	1.9	3.0	5.2	3.7	8.5
Fall TMAX	57.5	0.9	1.7	1.3	5.1	1.4	8.2

Temperature Extreme (days per year)

<32°F	155	-10	-11	-16	-25	-20	-43
<0°F	11	-4	-4	-7	-8	-7	-10
>90°F	1	1	2	4	11	6	29
>95°F	0	0	0	0	1	1	4
TMAX on hottest day of year	89.3	1.4	1.3	2.3	4.4	3.5	7.7
TMIN on coldest day of year	-11.9	3.7	4.0	5.7	9.4	7.3	16.1
Growing Season (days)	173	14	12	17	30	21	47

Precipitation (inches)

Annual mean	44.8	4.2	3.0	4.8	5.8	7.3	8.3
Winter mean	9.3	1.2	0.9	1.3	1.4	1.9	3.0
Spring mean	11.1	1.1	0.8	1.6	0.8	2.3	1.4
Summer mean	12.1	1.7	1.1	1.1	2.3	2.3	1.9
Fall mean	12.4	0.1	0.2	0.6	1.1	0.7	2.0

Extreme Precipitation (events per year)

1" in 24 hrs	11.2	1.6	1.6	2.3	3.1	2.9	4.1
2" in 48 hours	5.4	1.6	1.2	1.6	2.3	2.7	4.2

Extreme Precipitation (events per decade)

4" in 48 hours	3.4	2.9	0.4	2.1	3.8	5.3	6.4
Snow-Covered Days	93	-13	-13	-19	-34	-27	-48

*There were significant gaps in the daily data from some New Hampshire sites for the period 1980–2009. Instead, the historical values in these tables were derived from the downscaled GCM model output.

Nashua (1), New Hampshire

Indicators	Historical* 1980–2009	Change from historical (+ or -)					
		Short Term 2010–2039		Medium Term 2040–2069		Long Term 2070–2099	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions

Minimum Temperature (°F)

Annual TMIN	36.0	1.6	1.9	2.8	5.1	3.6	8.8
Winter TMIN	14.9	2.1	2.5	3.4	5.3	4.6	8.7
Spring TMIN	33.9	2.9	1.3	4.6	3.9	5.8	7.1
Summer TMIN	56.3	1.6	2.2	2.8	5.8	3.5	10.5
Fall TMIN	38.4	0.0	1.9	0.3	5.3	0.8	8.9

Maximum Temperature (°F)

Annual TMAX	59.0	1.7	1.8	3.0	4.9	3.9	8.3
Winter TMAX	35.8	1.6	1.6	2.4	3.5	3.4	6.0
Spring TMAX	57.5	2.6	1.5	5.0	4.7	6.7	8.6
Summer TMAX	81.0	1.7	2.1	3.3	5.7	4.1	9.5
Fall TMAX	61.4	0.8	1.8	1.2	5.5	1.4	8.8

Temperature Extreme (days per year)

<32°F	158	-9	-11	-15	-25	-19	-43
<0°F	11	-4	-5	-6	-8	-7	-10
>90°F	9	5	7	14	26	19	55
>95°F	1	2	2	5	10	9	29
TMAX on hottest day of year	94.4	2.0	1.3	3.6	5.1	5.4	8.9
TMIN on coldest day of year	-12.6	3.7	4.4	6.0	9.9	7.6	16.8
Growing Season (days)	167	13	14	17	29	19	49

Precipitation (inches)

Annual mean	44.8	4.3	2.6	5.5	4.3	7.3	6.2
Winter mean	10.9	1.1	0.9	1.4	1.1	2.0	2.5
Spring mean	11.2	1.0	0.9	1.6	1.1	2.1	1.7
Summer mean	11.0	1.7	0.6	1.3	1.3	2.1	0.9
Fall mean	11.8	0.5	0.1	1.0	0.6	1.1	1.1

Extreme Precipitation (events per year)

1" in 24 hrs	11.7	1.9	1.3	2.6	2.3	3.1	3.1
2" in 48 hours	4.6	1.4	0.8	2.0	1.6	2.3	3.0

Extreme Precipitation (events per decade)

4" in 48 hours	3.7	2.1	0.3	3.7	1.8	5.6	6.9
Snow-Covered Days	77	-14	-15	-19	-34	-27	-45

*There were significant gaps in the daily data from some New Hampshire sites for the period 1980–2009. Instead, the historical values in these tables were derived from the downscaled GCM model output.

Nashua (2), New Hampshire

Indicators	Historical* 1980–2009	Change from historical (+ or -)					
		Short Term 2010–2039		Medium Term 2040–2069		Long Term 2070–2099	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions

Minimum Temperature (°F)

Annual TMIN	36.2	1.7	1.9	2.8	5.0	3.6	8.6
Winter TMIN	15.3	2.1	2.3	3.4	5.1	4.6	8.5
Spring TMIN	33.8	2.8	1.5	4.4	4.1	5.6	7.2
Summer TMIN	56.5	1.6	2.1	2.8	5.7	3.5	10.4
Fall TMIN	38.7	0.3	1.7	0.6	5.1	1.0	8.5

Maximum Temperature (°F)

Annual TMAX	59.0	1.7	1.7	3.0	4.8	4.0	8.2
Winter TMAX	36.0	1.7	1.5	2.5	3.5	3.6	6.1
Spring TMAX	57.1	2.6	1.6	5.0	4.8	6.7	8.8
Summer TMAX	80.8	1.7	2.1	3.3	5.8	4.2	9.6
Fall TMAX	61.6	0.9	1.6	1.3	5.3	1.5	8.5

Temperature Extreme (days per year)

<32°F	157	-10	-11	-16	-25	-19	-43
<0°F	10	-4	-4	-6	-7	-7	-10
>90°F	9	5	7	14	26	19	54
>95°F	1	1	2	4	10	7	29
TMAX on hottest day of year	94.2	1.7	1.3	2.8	4.3	4.4	7.9
TMIN on coldest day of year	-11.9	3.8	4.3	6.1	9.7	7.7	16.4
Growing Season (days)	168	14	14	18	29	21	48

Precipitation (inches)

Annual mean	46.3	4.3	3.3	4.3	4.9	6.9	7.3
Winter mean	10.8	1.3	0.9	1.6	1.2	2.2	2.8
Spring mean	12.2	0.6	1.1	0.4	1.3	1.2	1.9
Summer mean	11.2	1.8	1.1	1.2	2.1	2.0	2.1
Fall mean	12.2	0.5	0.2	1.1	0.2	1.3	0.4

Extreme Precipitation (events per year)

1" in 24 hrs	12.3	1.5	1.5	1.5	2.3	2.4	3.4
2" in 48 hours	5.4	1.5	0.9	1.5	1.7	2.7	3.6

Extreme Precipitation (events per decade)

4" in 48 hours	5.3	1.6	-0.1	4.5	3.0	6.0	6.4
Snow-Covered Days	77	-14	-15	-19	-34	-27	-45

*There were significant gaps in the daily data from some New Hampshire sites for the period 1980–2009. Instead, the historical values in these tables were derived from the downscaled GCM model output.

Newport, New Hampshire

Indicators	Historical* 1980–2009	Change from historical (+ or -)					
		Short Term 2010–2039		Medium Term 2040–2069		Long Term 2070–2099	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions

Minimum Temperature (°F)

Annual TMIN	30.8	1.9	2.0	3.1	5.3	4.1	9.1
Winter TMIN	8.7	2.6	2.7	4.1	6.0	5.7	10.1
Spring TMIN	28.1	2.9	2.0	4.7	4.9	6.0	8.4
Summer TMIN	51.5	1.6	2.1	2.8	5.6	3.5	9.8
Fall TMIN	34.3	0.6	1.3	0.9	4.6	1.3	8.0

Maximum Temperature (°F)

Annual TMAX	55.8	1.8	1.7	3.1	4.9	4.1	8.4
Winter TMAX	32.1	2.0	1.6	2.9	3.7	4.1	6.5
Spring TMAX	53.8	2.4	1.8	4.9	5.1	6.5	9.1
Summer TMAX	78.1	1.7	2.1	3.4	6.0	4.3	10.0
Fall TMAX	58.6	1.2	1.4	1.6	5.0	1.7	8.2

Temperature Extreme (days per year)

<32°F	187	-9	-11	-15	-25	-18	-44
<0°F	27	-7	-6	-11	-15	-13	-22
>90°F	4	3	5	9	20	13	45
>95°F	0	1	1	1	5	2	17
TMAX on hottest day of year	92.2	1.2	1.8	2.2	5.2	3.6	9.8
TMIN on coldest day of year	-23.7	5.2	5.2	7.8	11.8	10.5	19.6
Growing Season (days)	139	7	10	17	27	20	46

Precipitation (inches)

Annual mean	39.9	3.4	3.3	4.2	5.9	6.0	8.3
Winter mean	8.3	1.0	0.7	0.9	1.1	1.5	2.5
Spring mean	9.6	1.0	1.5	1.8	1.7	1.8	2.6
Summer mean	11.3	1.5	0.9	1.0	1.9	2.1	1.5
Fall mean	10.7	0.0	0.3	0.4	1.0	0.6	1.7

Extreme Precipitation (events per year)

1" in 24 hrs	8.5	1.2	1.5	1.7	2.5	2.2	4.1
2" in 48 hours	3.1	1.0	0.9	0.8	1.6	1.8	3.1

Extreme Precipitation (events per decade)

4" in 48 hours	1.9	3.0	1.3	2.4	3.4	5.4	6.1
Snow-Covered Days	104	-12	-13	-18	-34	-26	-49

*There were significant gaps in the daily data from some New Hampshire sites for the period 1980–2009. Instead, the historical values in these tables were derived from the downscaled GCM model output.

Peterboro, New Hampshire

Indicators	Historical* 1980–2009	Change from historical (+ or -)					
		Short Term 2010–2039		Medium Term 2040–2069		Long Term 2070–2099	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions

Minimum Temperature (°F)

Annual TMIN	34.8	1.7	2.1	2.9	5.3	3.9	9.1
Winter TMIN	14.1	2.1	2.6	3.4	5.4	4.7	9.0
Spring TMIN	32.6	3.1	1.4	4.9	4.2	6.2	7.7
Summer TMIN	54.5	1.7	2.4	3.1	6.1	3.8	10.5
Fall TMIN	37.7	0.0	2.0	0.3	5.5	0.7	9.0

Maximum Temperature (°F)

Annual TMAX	56.8	1.5	1.6	2.7	4.5	3.6	7.7
Winter TMAX	33.5	1.6	1.6	2.3	3.4	3.4	6.0
Spring TMAX	55.7	2.5	1.5	4.8	4.5	6.5	8.2
Summer TMAX	78.2	1.5	1.8	2.9	4.9	3.6	8.3
Fall TMAX	59.2	0.8	1.8	1.1	5.3	1.3	8.4

Temperature Extreme (days per year)

<32°F	161	-9	-11	-16	-27	-20	-46
<0°F	12	-4	-4	-6	-9	-7	-11
>90°F	2	2	2	6	12	10	32
>95°F	0	0	0	1	1	3	8
TMAX on hottest day of year	90.1	2.1	1.2	3.6	4.7	5.2	8.8
TMIN on coldest day of year	-13.0	3.3	3.9	5.5	9.2	7.1	16.1
Growing Season (days)	158	13	13	17	31	20	54

Precipitation (inches)

Annual mean	43.6	4.4	3.2	5.5	4.8	6.6	7.7
Winter mean	10.0	1.2	1.2	1.4	1.5	1.9	3.0
Spring mean	10.8	1.0	1.2	1.4	1.2	1.6	2.3
Summer mean	11.8	2.3	0.7	2.0	1.4	2.4	1.3
Fall mean	11.1	0.0	0.1	0.6	0.4	0.5	1.1

Extreme Precipitation (events per year)

1" in 24 hrs	11.3	1.9	1.4	2.2	2.5	3.0	3.9
2" in 48 hours	5.5	1.7	1.4	2.2	2.0	2.7	4.4

Extreme Precipitation (events per decade)

4" in 48 hours	3.5	0.8	0.3	3.7	2.5	3.9	3.2
Snow-Covered Days	104	-12	-12	-19	-37	-28	-52

*There were significant gaps in the daily data from some New Hampshire sites for the period 1980–2009. Instead, the historical values in these tables were derived from the downscaled GCM model output.

Plymouth, New Hampshire

Indicators	Historical* 1980–2009	Change from historical (+ or -)					
		Short Term 2010–2039		Medium Term 2040–2069		Long Term 2070–2099	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions

Minimum Temperature (°F)

Annual TMIN	30.7	1.8	2.0	2.9	5.1	3.9	8.8
Winter TMIN	8.5	2.4	2.7	3.8	5.9	5.2	9.8
Spring TMIN	28.8	3.0	1.5	4.6	4.3	5.8	7.5
Summer TMIN	51.3	1.6	2.1	2.8	5.5	3.4	9.4
Fall TMIN	33.8	0.3	1.7	0.6	5.0	1.1	8.3

Maximum Temperature (°F)

Annual TMAX	55.1	1.8	1.8	3.1	4.9	4.1	8.4
Winter TMAX	30.6	1.9	1.7	2.7	3.6	3.8	6.3
Spring TMAX	53.5	2.6	1.7	5.0	4.8	6.7	8.8
Summer TMAX	78.3	1.8	2.0	3.4	5.7	4.3	9.6
Fall TMAX	57.7	1.0	1.6	1.4	5.3	1.6	8.7

Temperature Extreme (days per year)

<32°F	187	-9	-11	-16	-25	-19	-45
<0°F	26	-7	-7	-11	-15	-13	-22
>90°F	4	4	4	10	18	15	43
>95°F	0	1	1	2	4	3	15
TMAX on hottest day of year	92.1	1.8	1.4	3.0	4.5	4.0	8.8
TMIN on coldest day of year	-19.7	4.1	4.4	6.0	10.0	7.8	17.1
Growing Season (days)	140	7	11	16	29	20	49

Precipitation (inches)

Annual mean	43.1	4.2	2.4	4.9	4.9	6.9	7.4
Winter mean	9.8	1.1	0.7	1.1	1.2	1.7	2.5
Spring mean	10.5	1.1	0.8	1.5	1.4	1.7	2.8
Summer mean	11.6	1.5	0.4	0.9	1.2	2.3	0.5
Fall mean	11.3	0.5	0.4	1.2	0.9	1.1	1.6

Extreme Precipitation (events per year)

1" in 24 hrs	9.9	1.3	1.5	1.9	2.5	2.6	3.9
2" in 48 hours	3.9	1.4	1.0	1.4	1.8	2.4	3.5

Extreme Precipitation (events per decade)

4" in 48 hours	2.2	3.5	1.4	2.1	2.6	6.6	5.9
Snow-Covered Days	144	-10	-12	-16	-31	-26	-55

*There were significant gaps in the daily data from some New Hampshire sites for the period 1980–2009. Instead, the historical values in these tables were derived from the downscaled GCM model output.

Surry Mountain, New Hampshire

Indicators	Historical* 1980–2009	Change from historical (+ or -)					
		Short Term 2010–2039		Medium Term 2040–2069		Long Term 2070–2099	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions

Minimum Temperature (°F)

Annual TMIN	32.8	1.8	2.1	2.9	5.3	3.9	9.0
Winter TMIN	9.9	2.4	2.9	3.8	6.1	5.2	10.0
Spring TMIN	31.1	3.1	1.5	4.8	4.3	6.0	7.6
Summer TMIN	53.9	1.6	2.2	2.8	5.6	3.4	9.5
Fall TMIN	35.9	0.0	1.8	0.3	5.2	0.8	8.6

Maximum Temperature (°F)

Annual TMAX	56.3	1.7	1.7	2.9	4.7	3.9	8.1
Winter TMAX	32.4	1.7	1.7	2.5	3.6	3.6	6.1
Spring TMAX	54.8	2.6	1.6	5.0	4.7	6.7	8.6
Summer TMAX	78.4	1.7	2.0	3.1	5.5	3.9	9.0
Fall TMAX	59.2	0.8	1.8	1.2	5.2	1.3	8.4

Temperature Extreme (days per year)

<32°F	174	-9	-11	-15	-25	-18	-43
<0°F	23	-6	-6	-10	-14	-12	-20
>90°F	4	2	3	7	17	12	41
>95°F	0	0	1	1	2	2	11
TMAX on hottest day of year	91.5	1.5	1.1	2.4	3.8	3.9	7.2
TMIN on coldest day of year	-19.7	3.4	3.9	5.6	9.7	7.5	17.2
Growing Season (days)	154	9	10	15	26	17	46

Precipitation (inches)

Annual mean	41.4	4.3	2.6	5.2	4.6	7.1	6.3
Winter mean	8.9	0.9	0.7	1.1	1.0	1.6	2.2
Spring mean	9.8	1.1	0.4	1.8	0.6	2.2	1.0
Summer mean	12.5	1.7	1.4	1.3	2.5	2.2	2.2
Fall mean	10.3	0.5	0.0	0.8	0.3	1.0	0.8

Extreme Precipitation (events per year)

1" in 24 hrs	8.7	2.0	1.4	2.3	2.5	3.0	3.3
2" in 48 hours	3.8	1.1	0.7	1.2	1.5	2.3	3.0

Extreme Precipitation (events per decade)

4" in 48 hours	1.5	0.9	0.8	1.5	2.8	4.7	5.0
Snow-Covered Days	94	-11	-11	-17	-33	-24	-46

*There were significant gaps in the daily data from some New Hampshire sites for the period 1980–2009. Instead, the historical values in these tables were derived from the downscaled GCM model output.

Tamworth, New Hampshire

Indicators	Historical* 1980–2009	Change from historical (+ or -)					
		Short Term 2010–2039		Medium Term 2040–2069		Long Term 2070–2099	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions

Minimum Temperature (°F)

Annual TMIN	30.8	1.9	2.1	3.1	5.4	4.0	9.2
Winter TMIN	9.1	2.5	2.8	4.0	6.1	5.5	10.3
Spring TMIN	29.6	3.1	1.5	4.7	4.3	5.9	7.5
Summer TMIN	51.0	1.6	2.2	2.9	5.8	3.6	10.1
Fall TMIN	33.3	0.2	1.7	0.5	5.0	1.0	8.5

Maximum Temperature (°F)

Annual TMAX	55.3	1.7	1.7	3.0	4.8	3.9	8.2
Winter TMAX	31.6	1.8	1.5	2.5	3.4	3.6	6.0
Spring TMAX	54.0	2.4	1.6	4.7	4.6	6.3	8.4
Summer TMAX	78.3	1.8	2.1	3.4	6.0	4.3	10.2
Fall TMAX	56.9	0.9	1.5	1.3	5.1	1.5	8.2

Temperature Extreme (days per year)

<32°F	189	-9	-12	-17	-29	-20	-49
<0°F	26	-7	-7	-11	-15	-13	-22
>90°F	4	4	5	10	19	14	43
>95°F	1	0	0	1	5	3	18
TMAX on hottest day of year	92.4	1.8	1.7	3.2	5.6	5.2	11.1
TMIN on coldest day of year	-20.0	3.8	3.9	5.7	9.9	7.4	17.3
Growing Season (days)	138	8	9	17	27	20	48

Precipitation (inches)

Annual mean	51.2	5.7	3.0	7.2	7.8	9.7	10.8
Winter mean	11.6	1.3	0.9	1.5	1.4	2.4	2.7
Spring mean	12.7	1.7	1.3	2.5	2.5	2.4	3.4
Summer mean	13.6	1.9	0.6	1.0	2.3	3.0	2.0
Fall mean	13.2	0.9	0.4	2.1	1.6	1.9	2.8

Extreme Precipitation (events per year)

1" in 24 hrs	13.3	2.1	1.2	3.2	3.3	4.1	5.0
2" in 48 hours	6.6	2.2	1.3	3.0	3.4	3.6	5.2

Extreme Precipitation (events per decade)

4" in 48 hours	5.4	4.5	1.4	5.2	5.7	8.4	9.5
Snow-Covered Days	134	-13	-14	-18	-36	-30	-60

*There were significant gaps in the daily data from some New Hampshire sites for the period 1980–2009. Instead, the historical values in these tables were derived from the downscaled GCM model output.

Windham, New Hampshire

Indicators	Historical* 1980–2009	Change from historical (+ or -)					
		Short Term 2010–2039		Medium Term 2040–2069		Long Term 2070–2099	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions

Minimum Temperature (°F)

Annual TMIN	34.9	1.8	2.2	3.0	5.5	3.9	9.2
Winter TMIN	14.3	2.2	2.7	3.6	5.7	4.9	9.3
Spring TMIN	32.4	3.2	1.4	4.9	4.1	6.1	7.4
Summer TMIN	55.0	1.7	2.4	3.0	6.2	3.8	10.6
Fall TMIN	37.7	0.0	2.2	0.3	5.8	0.8	9.4

Maximum Temperature (°F)

Annual TMAX	60.1	1.6	1.7	2.9	4.8	3.9	8.2
Winter TMAX	36.6	1.6	1.6	2.3	3.5	3.4	5.9
Spring TMAX	58.3	2.7	1.4	5.0	4.6	6.8	8.6
Summer TMAX	82.0	1.7	1.9	3.2	5.4	4.0	9.4
Fall TMAX	63.0	0.8	2.0	1.2	5.8	1.5	9.1

Temperature Extreme (days per year)

<32°F	164	-9	-12	-16	-27	-20	-46
<0°F	13	-4	-5	-7	-9	-8	-12
>90°F	11	7	8	17	30	23	61
>95°F	2	2	1	5	10	10	31
TMAX on hottest day of year	95.3	2.3	1.5	3.7	5.6	5.3	10.5
TMIN on coldest day of year	-18.8	5.4	6.7	8.2	13.8	10.4	21.7
Growing Season (days)	157	11	11	17	30	19	53

Precipitation (inches)

Annual mean	44.4	4.4	3.5	5.7	6.0	7.0	9.3
Winter mean	10.4	1.2	0.8	1.4	1.2	1.6	2.7
Spring mean	10.7	1.1	1.5	1.7	2.0	2.0	3.3
Summer mean	10.8	1.8	1.1	1.6	2.1	2.3	2.1
Fall mean	12.5	0.4	0.1	0.9	0.6	1.1	1.2

Extreme Precipitation (events per year)

1" in 24 hrs	9.8	1.6	1.3	1.9	2.8	2.7	4.2
2" in 48 hours	5.0	1.7	1.2	2.2	2.4	2.9	3.8

Extreme Precipitation (events per decade)

4" in 48 hours	6.6	1.7	0.8	4.7	3.5	3.4	7.1
Snow-Covered Days	72	-14	-15	-19	-33	-27	-43

*There were significant gaps in the daily data from some New Hampshire sites for the period 1980–2009. Instead, the historical values in these tables were derived from the downscaled GCM model output.

ENDNOTES

- 1 National Research Council (2011) America's Climate Choices. Washington, DC: The National Academies Press. http://www.nap.edu/catalog.php?record_id=12781
- 2 There are several good books written over the past decade on the science of climate change, including (in reverse chronological order):

Archer, D. (2011) Global Warming: Understanding the Forecast. 2nd Edition. David Wiley-Blackwell. 212 p.

Schmidt, G., and J. Wolfe (2009) Climate Change: Picturing the Science. W.W. Norton.

Ruddiman, W. F. (2008) Earth's Climate: Past and Future (2nd Edition). New York: WH Freeman and Company. 388 p.

Weart, S. (2008) The Discovery of Global Warming: Revised and Expanded Edition. Cambridge, MA: Harvard University Press. 240 p.
<http://www.aip.org/history/climate/index.htm>

Kump, L.R., et al. (2004) The Earth System (2nd edition). New Jersey: Pearson-Prentice Hall. 420 p.

Steffen, W., et al. (2003) Global Change and the Earth System: A Planet Under Pressure. Springer, 336 p.

3 Intergovernmental Panel on Climate Change (IPCC) (2013) Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. T. F. Stocker, et al. (eds.). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. <http://www.ipcc.ch/report/ar5/wg1/>

Intergovernmental Panel on Climate Change (IPCC) (2007a) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. S. Solomon, et al. (eds.). Cambridge, UK: Cambridge University Press. 996 p.
http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html

National Academy of Sciences and The Royal Society (2014) Climate Change: Evidence & Causes. An Overview from the Royal Society and the US National Academy of Sciences. <http://dels.nas.edu/resources/static-assets/exec-office-other/climate-change-full.pdf>

4 National Climate Assessment and Development Advisory Committee (NCADAC) (2013) DRAFT Climate Assessment Report. Washington, DC: U.S. Global Change Research Program. <http://ncadac.globalchange.gov/>

National Research Council (2010) Advancing the science of climate change: America's climate choices. Washington, DC: National Academy Press. http://books.nap.edu/catalog.php?record_id=12782

Karl, T. R., J. M. Melillo, and T. C. Peterson (eds.) (2009) Global Climate Change Impacts in the United States. Cambridge University Press. <http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf>

5 IPCC, Climate Change 2013.

6 Many reports and peer reviewed scientific papers have documented recent trends in climate in the northeast United States. This includes:

New England Regional Assessment Group (2001) Preparing for a Changing Climate: The Potential Consequences of Climate Variability and Change. New England Regional Overview, U.S. Global Change Research Program, University of New Hampshire. 96 pp. www.globalchange.gov/what-we-do/assessment/previous-assessments/the-first-national-assessment-2000/first-national-climate-assessment-background-and-process/606

DeGaetano, A. T., and R. J. Allen (2002) Trends in twentieth-century temperature extremes across the United States. *Journal of Climatology*, 15, 3188–3205.

Hodgkins, G. A., I. C. James, and T. G. Huntington (2002) Historical changes in lake ice-out dates as indicators of climate change in New England, 1850–2000. *International Journal of Climatology*, v. 22, 1819–1827.

Keim, B. D., et al. (2003) Are there spurious temperature trends in the United States Climate Division Database? *Journal of Geophysical Research Letters*, 30(27), 1404. doi:10.1029/2002GL016295 30:1404

Huntington, T. G., et al. (2004) Changes in the proportion of precipitation occurring as snow in New England (1949 to 2000). *Journal of Climate*, 17, 2626–2636.

Hodgkins, G. A., R. W. Dudley, and T. G. Huntington (2003) Changes in the timing of high river flows in New England over the 20th century. *Journal of Hydrology*, 278: 244–252.

Trombulak, S. C., and R. Wolfson (2004) Twentieth-century climate change in New England and New York, USA. *Journal of Geophysical Research*, 31:L19202.

Wolfe, D. W., et al. (2005) Climate change and shifts in spring phenology of three horticultural woody perennials in the northeastern United States. *International Journal of Biometeorology*, 49, 303–309.

Wake, C., and A. Markham (2005) Indicators of Climate Change in the Northeast. Clean Air—Cool Planet Report. www.cleanair-coolplanet.org/information/pdf/indicators.pdf

UCS (2006) Union of Concerned Scientists—Climate Change in the U.S. Northeast. A Report of the Northeast Climate Impacts Assessment. October. <http://northeastclimateimpacts.org/>

Wake, C., et al. (2006) Cross Border Indicators of Climate Change over the Past Century. Climate Change Task Force, Gulf of Maine Council on the Marine Environment Report. www.gulfofmaine.org/council/publications/

Frumhoff, P. C., et al. (2007) Confronting climate change in the U.S. Northeast: Science, impacts, and solutions. Synthesis report of the Northeast Climate Impacts Assessment. Cambridge, MA: Union of Concerned Scientists (UCS). www.climatechoices.org

Hayhoe, K., et al. (2007) Past and future changes in climate and hydrological indicators in the U.S. Northeast. *Climate Dynamics*, 28, 381–407.

Burakowski, E. A., et al. (2008) Trends in Wintertime Climate in the Northeast United States, 1965–2005. *Journal of Geophysical Research*, 113, D20114. doi:10.1029/2008JD009870

Jacobson, G. L., et al. (2009) Maine's Climate Future: An Initial Assessment. Orono, ME: University of Maine. www.climatechange.umaine.edu/mainesclimatefuture/

Huntington, T. G., et al. (2009) Climate and hydrological changes in the northeastern United States: recent trends and implications for forested and aquatic ecosystems. *Canadian Journal of Forest Research*, 39: 199–212.

Rodenhouse, N. L., et al. (2009) Climate change effects on native fauna of northeastern forests. *Canadian Journal of Forest Research*, 39: 249–263.

Rustad L., et al. (2012) Changing climate, changing forests: The impacts of climate change on forests of the northeastern United States and eastern Canada. General Technical Report. NRS-99. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 48 p. www.nrs.fs.fed.us/pubs/41165

Hodgkins, G. (2013) The importance of record length in estimating the magnitude of climatic changes: an example using 175 years of lake ice-out dates in New England. *Climatic Change*, 119, 705–718. doi:10.1007/s10584-013-0766-8

7 Hayhoe, K., et al. (2008) Regional Climate Change Projections for the Northeast U.S. Mitigation and Adaptation Strategies for Global Change. 13, 425–436.

Stoner, A. M. K., et al. (2012) An asynchronous regional regression model for statistical downscaling of daily climate variables. *International Journal of Climatology*. doi: 10.1002/joc.3603

8 NCADAC, DRAFT Climate Assessment Report, 2013.

Wake, C. P., et al. (eds.) (2008) Special issue: assessment of climate change, impacts, and solutions in the Northeast United States. Mitigation and Adaptation Strategies for Global Change, 13(5–6), 419–660.

(Note: provided below are formal citations to the fourteen papers that were published in this Special Issue.)

Frumhoff, P. C., et al. (2008) An integrated climate change assessment for the Northeast United States. Mitigation and Adaptation Strategies for Global Change. 13(5–6), 419–423.

Hayhoe, K., et al. (2008) Regional Climate Change Projections for the Northeast U.S. Mitigation and Adaptation Strategies for Global Change. 13(5–6), 425–436.

Kirshen, P., et al. (2008) Coastal flooding in the Northeastern United States due to climate change. Mitigation and Adaptation Strategies for Global Change. 13(5–6), 437–451.

- Fogarty, M., et al. (2008) Potential climate change impacts on Atlantic cod (*Gadus morhua*) off the northeastern USA. *Mitigation and Adaptation Strategies for Global Change*. 13(5-6), 453-466.
- Ollinger, S. V., et al. (2008) Potential effects of climate change and rising CO₂ on ecosystem processes in northeastern U.S. forests. *Mitigation and Adaptation Strategies for Global Change*. 13(5-6), 467-485.
- Iverson, L., A. Prasad, and S. Matthews (2008) Modeling potential climate change impacts on the trees of the northeastern United States. *Mitigation and Adaptation Strategies for Global Change*. 13(5-6), 487-516.
- Rodenhouse, N. L., et al. (2008) Potential effects of climate change on birds of the Northeast. *Mitigation and Adaptation Strategies for Global Change*. 13(5-6), 517-540.
- Paradis, A., et al. (2008) Role of winter temperature and climate change on the survival and future range expansion of the hemlock woolly adelgid (*Adelges tsugae*) in eastern North America. *Mitigation and Adaptation Strategies for Global Change*. 13(5-6), 541-554.
- Wolfe, D. W., et al. (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.
- Scott, D., J. Dawson, and B. Jones (2008) Climate change vulnerability of the U.S. Northeast winter recreation-tourism sector. *Mitigation and Adaptation Strategies for Global Change*. 13(5-6), 577-596.
- Kunkel, K. E., et al. (2008) Sensitivity of future ozone concentrations in the northeast USA to regional climate change. *Mitigation and Adaptation Strategies for Global Change*. 13(5-6), 597-606.
- Ziska, L. H., P. R. Epstein, and C. A. Rogers (2008) Climate change, aerobiology, and public health in the Northeast United States. *Mitigation and Adaptation Strategies for Global Change*. 13(5-6), 607-613.
- Moomaw, W., and L. Johnston (2008) Emissions mitigation opportunities and practice in Northeastern United States. *Mitigation and Adaptation Strategies for Global Change*. 13(5-6), 615-642.
- Moser, S. C., et al. (2008) Adaptation to climate change in the Northeast United States: opportunities, processes, constraints. *Mitigation and Adaptation Strategies for Global Change*. 13(5-6), 643-659.
- 9 Dawson, J., and D. Scott (2013) Managing for climate change in the alpine ski sector. *Tourism Management*, 35, 244-254.
- Burakowski, E., and M. Magnusson (2012) Climate Impacts on the Winter Tourism Economy of the United States. Natural Resource Defense Council (NRDC) and Protect Our Winters (POW). www.nrdc.org/globalwarming/files/climate-impacts-winter-tourism-report.pdf
- 10 National Research Council (NRC) (2011). *Abrupt Impacts of Climate Change: Anticipating Surprises*. Washington, DC: The National Academies Press. www.nap.edu/catalog.php?record_id=18373
- 11 Wake, C. P., et al. (2011) Climate Change in the Piscataqua/Great Bay Region: Past, Present, and Future. Carbon Solutions New England Report for the Great Bay (New Hampshire) Stewards. www.carbonsolutionsne.org/
- 12 New Hampshire Climate Change Policy Task Force (2009) The New Hampshire Climate Action Plan: A Plan for New Hampshire's Energy, Environmental, and Economic Development Future. Prepared by NH Department of Environmental Services. http://des.nh.gov/organization/divisions/air/tsb/tps/climate/action_plan/nh_climate_action_plan.htm
- 13 NH Fish and Game Department (2013) Ecosystems and Wildlife Climate Adaptation Plan: Amendment to the NH Wildlife Plan. www.wildlife.state.nh.us/Wildlife/Wildlife_Plan/climate.html
- 14 More information on the NH Climate and Health Program is available from the Division of Public Health Services, NH Department of Health and Human Services. www.dhhs.nh.gov/dphs/index.htm
- 15 NH EPSCoR—Ecosystems and Society project. www.epscor.unh.edu/ecosystemsandsociety
- 16 Granite State Future project. www.granitestatefuture.org
- 17 NCADAC, DRAFT Climate Assessment Report, 2013.
- 18 U.S. Historical Climatology Network. <http://cdiac.ornl.gov/epubs/ndp/ushcn/ushcn.html>

- 19 In the 2011 report "Climate Change in the Piscataqua/Great Bay Region" (available at www.climatesolutionsne.org), minimum temperature records from Durham, New Hampshire, were not included because they showed significant inconsistencies (see write-up in Appendix A of the Piscataqua/Great Bay report for more details). The 2011 report used United States Historical Climatology Network (USHCN) Version 2.0 data. This current report uses the updated USHCN Version 2.5 data. The 2.5 version has an updated and more accurate pairwise homogenization algorithm (discussed in more detail at http://cdiac.ornl.gov/epubs/ndp/ushcn/monthly_doc.html) that has addressed the key issues we initially identified with the Durham minimum temperature record. We have therefore included all of the Durham data in this report.
- 20 IPCC, Climate Change, 2013.
- 21 Alexander, L. V., et al. (2006) Global observed changes in daily climate extremes of temperature and precipitation. *Journal of Geophysical Research*, 111, D05109. doi: 10.1029/2005JD006290
- 22 Paradis, A., et al. (2007) Role of winter temperature and climate change on the survival and future range expansion of the hemlock woolly adelgid (*Adelges tsugae*) in eastern North America. *Mitigation and Adaptation Strategies for Global Change*, 13: 541-554.
- 23 Lindgren, E., L. Talleklint, and T. Polfeldt (2000) Impact of climatic change on the northern latitude limit and population density of the disease transmitting European tick *Ixodes ricinus*. *Environmental Health Perspectives*, 108: 119-123.
- 24 Global Historical Climatology Network-Daily. www.ncdc.noaa.gov/oa/climate/ghcn-daily/
- 25 Brown, P. J., R. S. Bradley, and F. T. Keimig (2010) Changes in extreme climate indices for the northeastern United States, 1870-2005. *Journal of Climate*, 23, 6,555-6,572.
- 26 Frich, P., et. al. (2002) Observed coherent changes in climatic extremes during the second half of the twentieth century. *Journal of Climate Research*, 19: 193-212.
- Kunkel, K. E., et al. (2004) Temporal variations in frost-free season in the United States: 1895-2000. *Geophysical Research Letters*, 31, L03201. doi: 10.1029/2003 GL0186
- Cooter, E. J., and S. LeDuc (1995) Recent frost date trends in the Northeastern U.S. *International Journal of Climatology*, 15: 65-75.
- 27 Parmesan, C., and G. Yohe (2003) A globally coherent fingerprint of climate change impacts across natural systems. *Nature*, 421: 37-42.
- Walther, G. -P., et al. (2002) Ecological responses to recent climate change. *Nature*, 416: 389-395.
- 28 Huntington, T. G. (2004) Climate change, growing season length, and transpiration: plant response could alter hydrologic regime. *Plant Biology*, 6, 651-653.
- 29 USDA Plant Hardiness Zones. <http://planthardiness.ars.usda.gov>
- 30 Arbor Day Foundation. www.arborday.org/media/zones.cfm
- 31 Wolfe, D. W., et al. (2005) Climate change and shifts in spring phenology of three horticultural woody perennials in the northeastern United States. *International Journal of Biometeorology*.
- 32 Easterling, D. R., et al. (2000) Observed variability and trends in extreme climate events: A brief review. *Bulletin of the American Meteorological Society*, 81, 417-425.
- Groisman, P., et al. (2004) Contemporary Changes of the Hydrological Cycle over the Contiguous United States: Trends Derived from in situ Observations. *Journal of Hydrometeorology*, 5, 64-85.
- Hayhoe, K., et al. (2007) Past and future changes in climate and hydrological indicators in the U.S. Northeast. *Climate Dynamics*, 28: 381-407.
- Huntington, T. G. (2006) Evidence for intensification of the global water cycle: review and synthesis. *Journal of Hydrology*, 319: 83-95.
- Trenberth, K. E., et al. (2003) The changing character of precipitation, *Bulletin of the American Meteorological Society*, 84, 1205-1217.
- 33 USHCN quality control. cdiac.ornl.gov/epubs/ndp/ushcn/daily_doc.html
- 34 Bradbury, J., S. L. Dingman, and B. D. Keim (2002) New England Drought and Relations with Large Scale Atmospheric Circulation Patterns. *Journal of the American Water Resources Association*, 38(5): 1287-1299.

- Namias, J. (1966) Nature and Possible Causes of the Northeastern United States Drought During 1962–1964. *Monthly Weather Review*, 94 (9): 543–554.
- 35 Spierre, S. G., and C. P. Wake (2010) Trends in Extreme Precipitation Events for the Northeastern United States, 1948–2007. Carbon Solutions New England and Clean Air Cool Planet. Durham, NH. www.climatesolutionsne.org/
- 36 Burakowski, E. A., et al. (2008) Trends in wintertime climate in the northeastern United States: 1965–2005. *Journal of Geophysical Research*, 113: D20114. doi: 10.1029/2008JD009870
- 37 Brown, R. D., and P. W. Mote (2009) The Response of Northern Hemisphere Snow Cover to a Changing Climate. *Journal of Climate*, 22: 2124–2145.
- 38 Hodgkins, G. (2013) The importance of record length in estimating the magnitude of climatic changes: an example using 175 years of lake ice-out dates in New England. *Climatic Change*, 119: 705–718. doi: 10.1007/s10584-013-0766-8
- Hodgkins, G. A. (2010) Historical Ice-Out Dates for 29 Lakes in New England, 1807–2008. United States Geological Survey Open File Report 2010–1214. 38 p. <http://pubs.usgs.gov/of/2010/1214/pdf/ofr2010-1214.pdf>
- Hodgkins, G. A., I. C. James II, and T. G. Huntington (2002) Historical changes in lake ice-out dates as indicators of climate change in New England, 1850–2000. *International Journal of Climatology*, 22: 1819–1827.
- Magnuson, J. J., et al. (2000) Historical trends in lake and river ice cover in the Northern Hemisphere. *Science*, 289, 1743–1746.
- 39 Maeda, O., and S. E. Ichimura (1973) On the high density of a phytoplankton population found in a lake under ice. *Internationale Revue der Gesamten Hydrobiologie*, 58: 673–685.
- 40 Stewart, K. M. (1976) Oxygen deficits, clarity and eutrophication in some Madison lakes. *Internationale Revue der Gesamten Hydrobiologie*, 61: 563–579.
- 41 Hodgkins, G., The importance of record length in estimating the magnitude of climatic changes, 2013.
- 42 Wang, Jia, et al. (2012) Temporal and Spatial Variability of Great Lakes Ice Cover, 1973–2010. *Journal of Climate*, 25, 1318–1329. doi: <http://dx.doi.org/10.1175/2011JCLI4066.1>
- 43 Data from FEMA. www.fema.gov/disasters/grid/state-tribal-government.
- 44 NCADAC, DRAFT Climate Assessment Report, 2013.
- 45 Stoner, A. M. K., et al., An asynchronous regional regression model, 2012.
- 46 New Hampshire EPSCoR Data Discovery Center. <http://epscor-ddc.sr.unh.edu>
- 47 Burakowski et al., Trends in Wintertime Climate in the Northeast United States, 2008.
- 48 See all references listed in Endnote 8.
- 49 Northeast Climate Impacts Assessment (NECIA). www.climatechoices.org/ne/index.html
- 50 Wolfe et al., Projected change in climate thresholds in the Northeastern U.S., 2008.
- Hatfield, J., and G. Takle (2013) Agriculture (Chapter 6) in NCADAC (2013) DRAFT Climate Assessment Report. Washington, DC: U.S. Global Change Research Program. <http://ncadac.globalchange.gov/>
- 51 Ziska, L. H. (2003) Evaluation of the growth response of six invasive species to past, present and future atmospheric carbon dioxide. *Journal of Experimental Botany*, 54, 395–404.
- Ziska, L. H. (2009) Changes in competitive ability between a C4 crop and a C3 weed with elevated carbon dioxide. *Weed Science*, 49, 622–627.
- 52 Bradley, B. A., D. S. Wilcove, and M. Oppenheimer (2010) Climate change increases risk of plant invasion in the Eastern United States. *Biological Invasions*, 12, 1855–1872.
- 53 Klinedinst, P.L., et al. (1993) The potential effects of climate change on summer season dairy cattle milk production and reproduction. *Climate Change*, 23: 21–36.
- 54 Ziska, L. H., et al. (2007) Rising atmospheric carbon dioxide and potential impacts on the growth and toxicity of poison ivy (*Toxicodendron radicans*). *Weed Science*, 55: 388–292.
- Mohan, J. E., et al. (2006) Biomass and toxicity responses of poison ivy (*Toxicodendron radicans*) to elevated atmospheric CO₂. *Proceedings of the National Academy of Sciences*, 103: 9086–9089.

- 55 Ziska, L. H., P. R. Epstein, and C.A. Rogers (2008) Climate change, aerobiology and public health in the Northeast United States. *Mitigation and Adaptation Strategies for Global Change*, 13: 607-613.
- 56 NCADAC, DRAFT Climate Assessment Report, 2013.
- 57 Hayhoe et al., Regional Climate Change Projections, 2008.
- 58 *Ibid.*
- 59 National Research Council (NRC) (2011) America's Climate Choices. Washington, DC: The National Academies Press.
www.nap.edu/catalog.php?record_id=12781
- 60 Wake, C., et al. (2011) Collaborative and Transparent Production of Decision-Relevant Information for New Hampshire's Climate Action Plan. *The Northeastern Geographer*, 3, 1-21.

Frumhoff, P. C., et al. Confronting climate change in the U.S. Northeast, 2007.

Wake, C., et al. (2009) Climate Change in the Casco Bay Watershed: Past, Present, and Future. Report for the Casco Bay Estuaries Project, University of Southern Maine. www.cascobay.usm.maine.edu/
- 61 NCADAC, DRAFT Climate Assessment Report, 2013.

NRC, America's Climate Choices, 2011.
- 62 IPCC, Climate Change, 2013.
- 63 NRC, America's Climate Choices, 2011.
- 64 IPCC (2007b) Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. M. L. Parry, et al. (eds.) Cambridge, United Kingdom, and New York, NY, USA: Cambridge University Press. <http://www.ipcc.ch>

IPCC (2007c) Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007. B. Metz et al. (eds.). Cambridge, United Kingdom, and New York, NY, USA: Cambridge University Press. <http://www.ipcc.ch>
- 65 The IPCC Working Group II and III Fifth Assessment Reports should be available in the spring of 2014 online at: <http://www.ipcc.ch>.
- 66 National Research Council (2010) Advancing the Science of Climate Change. Washington, DC: The National Academies Press.
http://www.nap.edu/catalog.php?record_id=12782

National Research Council (2010) Adapting to the Impacts of Climate Change. Washington, DC: The National Academies Press.
http://www.nap.edu/catalog.php?record_id=12783

National Research Council (2010) Informing an Effective Response to Climate Change. Washington, DC: The National Academies Press.
http://www.nap.edu/catalog.php?record_id=12784

National Research Council (2010) Limiting the Magnitude of Future Climate Change. Washington, DC: The National Academies Press.
http://www.nap.edu/catalog.php?record_id=12785

NCADAC, DRAFT Climate Assessment Report, 2013.
- 67 New Hampshire Climate Change Policy Task Force, The New Hampshire Climate Action Plan, 2009.
- 68 Wake, et al., Collaborative and Transparent Production of Decision-Relevant Information, 2011.
- 69 The goal of reducing emissions of heat-trapping gases by 80 percent below 1990 levels has been adopted by several cities, states, and organizations including the New England Governors and Eastern Canadian Premiers, and all five other New England states. More information at: www.c2es.org/us-states-regions/policy-maps/climate-action-plans
- 70 Wake, C. P., et al. (2012) New Hampshire's Energy, Environmental, and Economic Development Benchmark Report. NH Energy and Climate Collaborative.
<http://nhcollaborative.org/benchmarkreport/>
- 71 Regional Greenhouse Gas Initiative <http://www.rggi.org>

NH Greenhouse Gas Emission Reduction Fund
[www.puc.nh.gov/Sustainable Energy/GHGERF.htm](http://www.puc.nh.gov/Sustainable%20Energy/GHGERF.htm)

www.nhcdfa.org/resources/publications-and-forms/docs/35

NH Core Energy Efficiency Programs
[www.puc.state.nh.us/electric coreenergyefficiencyprograms.htm](http://www.puc.state.nh.us/electric/coreenergyefficiencyprograms.htm)

New Hampshire Office of Energy and Planning
www.nh.gov/oep/

- Economic and Greenhouse Gas Impacts of the New 2009 Fuel Economy (CAFE) Standards in New England
http://carbonsolutionsne.org/resources/reports/pdf/2009_cafe_final.pdf
- Jordan Institute www.jordaninstitute.org
- UNH EcoLine
www.unh.edu/news/cj_nr/2010/jan/bp19ecoline.cfm
- ReVision Energy www.revisionenergy.com/index.php
- Revolution Energy www.rev-en.com
- 72 Vermont Energy Investment Corporation (2011) Independent Study of Energy Policy Issues: Key Findings and Recommendations. Report prepared for New Hampshire Public Utility Commission. [www.puc.state.nh.us/SustainableEnergy/Reports/Key Findings & Recommendations - NH Independent Study of Energy Policy Issues_09-30-11.pdf](http://www.puc.state.nh.us/SustainableEnergy/Reports/KeyFindings&Recommendations-NHIndependentStudyofEnergyPolicyIssues_09-30-11.pdf)
- 73 Energy Efficiency and Sustainable Energy (EESE) Board (2012) Final Report on the New Hampshire Independent Energy Study [www.puc.nh.gov/EESE Board/Annual Reports/VEIC - EESE Board Report - FINAL FULL 113012.pdf](http://www.puc.nh.gov/EESEBoard/AnnualReports/VEIC-EESEBoardReport-FINALFULL113012.pdf)
- 74 Granite State Future—Regional Plan Framework www.granitestatefuture.org/files/7713/6607/4082/RegionalPlanFramework.pdf
- 75 FEMA Community Rating System www.fema.gov/national-flood-insurance-program/national-flood-insurance-program-community-rating-system
- 76 Dover Partners: Great Bay National Estuarine Research Reserve, University of New Hampshire, Massachusetts Institute of Technology, Consensus Building Institute. For more info: <http://necap.mit.edu/necap/>
- 77 Partners: NH Coastal Adaptation Workgroup. For more information: www.cascobay.usm.maine.edu/pdfs/cre_coast_final_report.pdf
- 78 Partners: NH Sea Grant, UNH Cooperative Extension, NH Coastal Adaptation Workgroup.
- 79 Partners: Great Bay National Estuarine Research Reserve, University of New Hampshire, NH Listens, Geosyntec Consulting. For more info: www.capenh.net
- 80 Partners: Strafford Regional Planning Commission, University of New Hampshire. For more info: www.ci.durham.nh.us/administration/climate-adaptation-chapter
- 81 Partners: University of New Hampshire, Great Bay National Estuarine Research Reserve, NH Sea Grant. For more information on the new 100 year floodplain maps and the Vermont Law School Report: <http://100yearfloods.org>
- 82 City of Portsmouth – Coastal Resiliency Initiative: <http://www.planportsmouth.com/cr/>
- 83 Keene Cities for Climate Protection Committee www.ci.keene.nh.us/sustainability/climate-change
- 84 Adaptation Toolkit for New Hampshire Communities <http://des.nh.gov/organization/divisions/air/tsb/tps/climate/toolkit/index.htm>
- 85 Climate Adaptation Knowledge Exchange www.cakex.org
- 86 Extreme Precipitation in New York and New England <http://precip.eas.cornell.edu>
- 87 Forging the Link: Linking the Economic Benefits of Low Impact Development and Community Decisions www.unh.edu/unhsc/forgingthelink
- 88 Georgetown Climate Center www.georgetownclimate.org/adaptation/overview
- 89 Home Grown: The Economic Impact of Local Food Systems in New Hampshire http://foodsolutionsne.org/sites/foodsolutionsne.org/files/HomeGrownReport_final.pdf
- 90 Infrastructure and Climate Network (ICNet) <http://theicnet.org>
- 91 NH Building Energy Code Compliance Roadmap Report www.nhenergycode.com/live/index.php?go=roadmap
- 92 NH Granit <http://www.granit.unh.edu>
- 93 New Hampshire Lives on Water www.nh.gov/water-sustainability/publications/documents/wsc-final-report.pdf
- 94 New Hampshire Local Energy Solutions www.nhenergy.org
- 95 NH Office of Energy and Planning—Cost of Sprawl Tool www.costofsprawl.org
- 96 New Hampshire's Changing Landscape <http://clca.forestsociety.org/nhcl/>

- 97 New Hampshire Storm Smart Coast
<http://nh.stormsmart.org>
- 98 U.S. DOT Transportation and Climate Change
Clearinghouse <http://climate.dot.gov/about/index.html>
- 99 Upper Valley Adaptation Workgroup
www.uvlsrpc.org/resources/uvaw/
- 100 U.S. Historical Climatology Network
<http://cdiac.ornl.gov/epubs/ndp/ushcn/ushcn.html>
- 101 Menne, M. J., C. N. Williams, Jr., and R. S. Vose (2009) The
U.S. Historical Climatology Network Monthly Temperature
Data, Version 2. *Bulletin of the American Meteorological
Society*, 90(7): 993-1007.

Menne, M. J., and C. N. Williams, Jr. (2009)
Homogenization of Temperature Series via Pairwise
Comparisons. *Journal of Climate*, 22: 1700-1717.
- 102 Global Historical Climatology Network-Daily
www.ncdc.noaa.gov/oa/climate/ghcn-daily/
- 103 Durre, I., et al. (2010) Comprehensive Automated Quality
Assurance of Daily Surface Observations. *Journal of
Applied Meteorology and Climatology*, 49: 1615-1633.
- 104 Brown, P. J., R. S. Bradley, and F. T. Keimig (2010)
Changes in extreme climate indices for the northeastern
United States, 1870-2005. *Journal of Climate*, 23, 6,555-
6,572.
- 105 NH EPSCoR – Data Discover Center
<http://epscor-ddc.sr.unh.edu>
- 106 Gilbert, R. O. (1987) Statistical Methods for Environmental
Pollution Monitoring. Van Nostrand Rienhold Company,
Inc.; New York.

Burkey, J. (2006) A non-parametric monotonic trend
test computing Mann-Kendall Tau, Tau-b, and Sen's Slope
written in Mathworks-MATLAB implemented using matrix
rotations. King County, Department of Natural Resources
and Parks, Science and Technical Services section.
Seattle, Washington, USA. [http://www.mathworks.com/
matlabcentral/fileexchange/authors/23983](http://www.mathworks.com/matlabcentral/fileexchange/authors/23983)
- 107 Meehl, G. A., et al. (2007) The WCRP CMIP3 multi-model
dataset: A new era in climate change research. *Bulletin of
the American Meteorological Society*, 88: 1383-1394.
- 108 Nakicenovic, N., et al. (2000) IPCC Special Report on
Emissions Scenarios. Cambridge, UK, and New York, NY,
USA: Cambridge University Press. 599 p.
- 109 Peters, G. P., et al. (2013) The challenge to keep global
warming below 2°C. *Nature Climate Change*, 3: 4-6.
doi:10.1038/nclimate1783

Peters, G., et al. (2012) CO2 emissions rebound after the
Global Financial Crisis. *Nature Climate Change* 2: 2-4 doi.
10.1038/nclimate1332

Raupach, M. R., et al. (2007) Global and regional drivers
of accelerating CO2 emissions PNAS 2007 104(24),
10288-10293. doi:10.1073/pnas.0700609104
- 110 Meinshausen, M., et al. (2009) Greenhouse-gas emission
targets for limiting global warming to 2°C. *Nature* 458,
1158-1163. doi:10.1038/nature08017
- 111 Randall, D.A., et al. 2007: Climate Models and Their
Evaluation. Climate Change 2007: The Physical Science
Basis. Contribution of Working Group I to the Fourth
Assessment Report of the Intergovernmental Panel on
Climate Change [Solomon, S., et al. (eds.)]. Cambridge,
United Kingdom, and New York, NY, USA: Cambridge
University Press, 996 p.
- 112 IPCC, Climate Change, 2013.
- 113 Meehl et al., The WCRP CMIP3 multi-model dataset, 2007.
- 114 IPCC, Climate Change, 2007a.
- 115 Due to the decision of IPCC Working Group 1 to focus on
the A2, A1B, and B1 scenarios for the Fourth Assessment
Report (2007), only four GCMs had A1FI scenarios
available. For other models, daily outputs were not
available for all scenarios.
- 116 Knutti, R., and G. C. Hegerl (2008) The equilibrium
sensitivity of the Earth's temperature to radiation
changes. *Nature Geoscience*, 1, 735-743. doi:10.1038/
ngeo337
- 117 Overland, J. E., et al. (2011) Considerations in the
Selection of Global Climate Models for Regional
Climate Projections: The Arctic as a Case Study.
Journal of Climate, 24, 1583-1597. doi: [http://dx.doi.
org/10.1175/2010JCLI3462.1](http://dx.doi.org/10.1175/2010JCLI3462.1)
- 118 Knutti, R., et al. (2010) Challenges in combining
projections from multiple models. *Journal of Climate*, 23,
2739-2758. doi: 10.1175/2009JCLI3361.1

Randall et al., Climate Models and Their Evaluation, 2007.
- 119 Grotch, L., and M. C. MacCracken (1991) The use of
general circulation models to predict regional climatic
change. *Journal of Climate*, 4, 286-303.

- 120 Stoner, A. M. K., et al., An asynchronous regional regression model, 2012.
- 121 Vrac, M., et al. (2007) A general method for validating statistical downscaling methods under future climate change. *Geophysical Research Letters*, 34, L18701. doi:10.1029/2007GL030295
- National Academy of Sciences (2013) Abrupt Impacts of Climate Change: Anticipating Surprises. Washington, DC: National Academy Press.
www.nap.edu/catalog.php?record_id=18373
- 122 Stoner, A. M. K., et al., An asynchronous regional regression model, 2012.
- 123 Durre, I., et al. (2010) Comprehensive Automated Quality Assurance of Daily Surface Observations. *Journal of Applied Meteorology and Climatology*, 49, 1615–1633.
- 124 Hawkins, E., and R. Sutton (2009) The Potential to Narrow Uncertainty in Regional Climate Predictions. *Bulletin of the American Meteorological Society*, 90, 1095–1107.
- Hayhoe, K. (2013) High-resolution climate projections: Where do they come from and what can we do with them? Infrastructure and Climate Network (ICNet). Webinar recorded on 18 September 2013.
www.theicnet.org/webinars/archive/09-18-13
- 125 Weigel, A. P., et al. (2010) Risks of Model Weighting in Multimodel Climate Projections. *Journal of Climate*, 23, 4175–4191. doi: 10.1175/2010JCLI3594.1
- Knutti, R., et al. (2010) Challenges in combining projections from multiple climate models. *Journal of Climate*, 23, 2739–2758.
- 126 Stott, P. A., and J. A. Kettleborough (2002) Origins and estimates of uncertainty in predictions of twenty-first century temperature rise. *Nature*, 416(6882), 723–6.



Climate Solutions New England (CSNE) promotes regional collaboration toward the goal of greater energy self-reliance and weather resilience that contribute to healthy, prosperous, and sustainable communities across New England. CSNE is an initiative of and led by faculty and staff from the Sustainability Institute and the University of New Hampshire.

Learn more at www.climatesolutionsne.org.

the sustainability institute

at the University of New Hampshire

Sustainability is a core value of UNH, shaping culture, informing behavior, and guiding work. As a nationally recognized leader, the Sustainability Institute acts as convener, cultivator, and champion of sustainability on campus, in the state and region, and around the world.

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APPENDIX IV- RESOURCES

Emergency Response and Climate Adaptation Resources

Adaptation Toolkit for New Hampshire Communities provides communities with a path to plan for future extreme weather events.

<http://des.nh.gov/organization/divisions/air/tsb/tps/climate/toolkit/index.htm>

The Climate Adaptation Knowledge Exchange features a vast library of concise case studies of climate adaptation from around the country and the world. It also provides links to funding sources for adaptation.

<http://www.cakex.org/>

Extreme Precipitation in New York and New England provides an updated extreme precipitation analysis via an interactive web tool.

<http://precip.eas.cornell.edu>

The Georgetown Climate Center provides resources to help communities prepare for climate change, including the Adaptation Clearinghouse, Adaptation Tool Kits, lessons learned, and case studies.

www.georgetownclimate.org/adaptation/overview

The Infrastructure and Climate Network (ICNet) is dedicated to accelerating climate science and engineering research in the Northeastern United States. It focuses on climate change and sea level rise impacts and adaptation for sustainable bridges, roads, and transportation networks.

<http://theicnet.org>

New Hampshire's Changing Landscape explores the relationships between population growth, land use change, and the impact of development upon the state's natural resources, including our forest and agricultural lands, critical water supply resources, and biodiversity.

<http://clca.forestsociety.org/nhcl/>

New Hampshire Storm Smart Coast provides a well developed example of a web resource dedicated to helping community decision makers address the challenges of storms, flooding, sea level rise, and climate change. The website also features efforts by the NH Coastal Adaptation Workgroup (NHCAW), a collaboration of nineteen organizations working to help communities in New Hampshire's Seacoast area prepare for the effects of extreme weather events and other effects of long-term climate change. NHCAW provides communities with education, facilitation, and guidance.

<http://nh.stormsmart.org>

Transportation and Climate Change Clearinghouse is the U.S. Department of Transportation

website that provides information on transportation and climate change.

<http://climate.dot.gov/about/index.html>

Upper Valley Adaptation Workgroup is building climate resilient communities in the Upper Valley through research, information sharing, and education.

www.uvlsrc.org/resources/uvaw/

APPENDIX V- ENDNOTES

¹ *Climate Change in Southern New Hampshire Past, Present, and Future*. 2014. Climate Solutions New England Sustainability Institute

² http://www.ucsusa.org/global_warming/science_and_impacts/impacts/northeast-climate-impacts.html#.VJEpwdLF-Ag

³ *Climate Change Impacts in the United States: The Third National Climate Assessment*. 2014. U.S. Global Change Research Program

⁴ *Climate Change in Southern New Hampshire Past, Present, and Future*. 2014. Climate Solutions New England Sustainability Institute

⁵ *Stormwater Drainage System Vulnerability, Capacity, and Cost Under Population Growth and Climate Change, Lake Sunapee Watershed, New Hampshire*. April 2012. Syntectic International, LLC

⁶ *The New Hampshire Climate Action Plan: A Plan for New Hampshire's Energy, Environmental and Economic Development Future*. March 2009. NH Department of Environmental Services

⁷ *Climate Change in Southern New Hampshire Past, Present, and Future*. 2014. Climate Solutions New England Sustainability Institute