

# Climate Change and Human Health in New Hampshire

## AN IMPACT ASSESSMENT

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### Cameron Wake

Climate Solutions New England  
Earth System Research Center  
Institute for the Study of Earth, Oceans and Space (EOS)  
University of New Hampshire, Durham, NH

### John Bucci

School of Marine Science and Ocean Engineering  
University of New Hampshire, Durham, NH

### Semra Aytur

Department of Health Management and Policy  
University of New Hampshire, Durham, NH

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## Methodology

This report consists of a review of selected, relevant literature that can enable stakeholders to better understand the global-to-local public health impacts of climate change. It is not intended to serve as a comprehensive review of the literature. The literature on climate change and health is vast and dynamic, and we suggest that subject matter experts be consulted for more detailed information, particularly on local health impacts. We relied on peer-reviewed, published scientific literature and federal reports. References to gray literature (e.g., state agency reports, conference presentations, posters, PowerPoint presentations, and informal communication) are not included.

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University of New Hampshire  
107 Nesmith Hall  
Durham, NH 03824



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## EXECUTIVE SUMMARY

### Background

Climate change threatens human health in many ways. The negative impacts of climate change on human health are likely to increase in both magnitude and frequency as the climate system continues to change in response to ever increasing global emissions of heat-trapping gases released from a variety of human activities.<sup>1</sup> The Centers for Disease Control and Prevention (CDC) Building Resilience Against Climate Effects (BRACE) framework<sup>2</sup> provides guidance to states and cities to develop strategies and programs to confront the health implications of climate change. This report serves to address Steps 1 and 2 of the BRACE framework via an assessment of past and future climate change across New Hampshire combined with an assessment of the impact of climate change on human health.

A key component of the BRACE framework is building resilience. In public health, resilience is a measure of a community's ability to utilize available resources to respond to, withstand, and recover from adverse situations.<sup>3</sup> More generally, people think of resilience as the ability to recover, persist, or thrive amid change. The New Hampshire Climate and Health Workgroup has tentatively developed the following definition: *Resilience is the ability and capacity to anticipate, prepare for, respond to, and recover from significant threats with minimum damage to human health and well-being, the economy, and the environment.*<sup>4</sup>

The importance of the way we plan our built environment—including land use, transportation, and water management decisions, as well as how we interact with our natural environment and preserve its life-supporting functions—must be emphasized as pivotal points of intersection as we develop climate adaptation strategies.

Notably, a resilience-based approach to climate change adaptation should align with New Hampshire's transformative State Health Improvement Plan.<sup>5</sup> That plan underscores the importance of cross-sector collaboration and coordinated strategies to address the social and environmental determinants of health. These strategies not only support healthy communities for all New Hampshire residents, but they are also critically important for reducing health care costs<sup>6</sup> and reducing the burden of disease.

### Past and Future Climate Change in New Hampshire<sup>7</sup>

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 (i.e., coal, oil, and natural gas) for energy, clearing of forested lands for agriculture, and raising livestock—are now the primary drivers of change

in the Earth's climate system. Here we 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 resulting from human activities.

Detailed information on how climate has changed across New Hampshire over the past century is provided in a series of recent climate assessments for the state.<sup>8</sup> Overall, 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 five U.S. Historical Climatology Network meteorological stations<sup>9</sup> (Bethlehem, Durham, First Connecticut Lake, Hanover, Keene) and dozens of Global Historical Climatology Network meteorological stations<sup>10</sup> show that since 1970:

- Average annual maximum temperatures have warmed 0.5 to 2.6°F (depending on the station) with the greatest warming occurring in fall or winter.
- The number of days with minimum temperatures less than 32°F has decreased, and the coldest winter nights have warmed.
- The length of the growing season is two to five weeks longer.
- Annual precipitation has increased by 7 to 20 percent.
- Extreme precipitation events have increased across the region; this increase has been dramatic at some sites. 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 across New Hampshire.

In addition, more than a century of observations shows that spring lake ice-out dates across New Hampshire are occurring one to two weeks earlier today than in the past.<sup>11</sup>

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 utilizing 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 emissions in the year 2000 by the end of the century. Although both scenarios are possible, the current global emissions trend from 2000 through 2014 suggests that, in the absence of concerted 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 New Hampshire. Depending on the 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 in New Hampshire 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 (i.e., heat waves) 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.

Annual average precipitation is projected to increase 14 to 20 percent by end-of-century compared to the historical average from 1980 to 2009. Larger increases are expected for winter and spring, exacerbating concerns regarding rapid snowmelt, high peak stream flows, and flood risk. New Hampshire can also expect to experience more extreme precipitation events in the future. For example, under the high emissions scenario, the number of events that drop more than four inches of precipitation in 48 hours are projected to increase two- to three-fold across much of New Hampshire by the end of the century. A summary of the historical and projected future 30-year climatologies are provided for southern New Hampshire (Table ES-1) and northern New Hampshire (Table ES-2) for the historical period (1980–2009) and the future (near-term [2010–2039], medium-term [2040–2069], and long-term [2070–2099]).

## Health Impacts

The potential impact of climate change on human health provided in this report is organized by the type of health impact (following the CDC BRACE framework):

- Temperature, heat events, and heat stress injury/death
- Extreme weather and injury/death
- Temperature, air quality, and respiratory and cardiovascular illness
- Pollen, mold, and allergies
- Temperature, precipitation, and vector-borne diseases
- Temperature, precipitation, severe weather, and foodborne diseases
- Temperature, precipitation, and waterborne diseases
- Climate change, health behaviors, and chronic disease
- Climate change, mental health, and stress-related disorders

The potential primary and secondary health impacts of climate change for New Hampshire, as well as equity considerations and identification of vulnerable populations, are listed in Table ES-3 and summarized below.

### Heat Stress

Heat-related morbidity and mortality is a growing public health concern as demographic shifts in New England (such as an aging population and increasing urbanization) combine with the projection of more frequent heat waves, making the region particularly vulnerable. As reported in the recent White House Report on the health impacts of climate change on Americans,<sup>12</sup> heat-related mortality and morbidity already represents a significant health impact, and the northeastern United States is likely to be particularly vulnerable in the future. Although data on the specific number of heat-related hospitalizations and deaths in New Hampshire were unavailable at the time of this report, the New Hampshire Department of Health and Human Services - Environmental Public Health Tracking (EPHT) system and other surveillance efforts are expected to support such analyses in the future.

We can also make educated assessments about how projected changes in climate may affect the state, based

on published studies from other northeastern states. For example, in New Hampshire, the projected increase in the frequency of hot days (Tables ES-1 and ES-2) and the associated increase in heat stress will likely lead to more heat injuries and deaths. Based on the assumption that the mortality rate is related to the projected increase in the number of days where maximum temperature is greater than 95°F and using the conservative 2012 New York City base rate of 0.11 deaths per 100,000, the fatality rate could increase more than an order of magnitude across New Hampshire by the end of the century under the high emissions scenario.

### **Extreme Weather Events and Injury/Death**

Extreme weather events can lead to morbidity and mortality associated with flooding, storms, exposure to contaminants left in the wake of storm events, and exacerbation of pre-existing conditions when persons are displaced and/or unable to obtain medications, supplies, and health services following storm events. Additional indirect health impacts associated with extreme weather events include degradation of water quality and increases in emerging disease (e.g., pathogens), contaminated seafood, and harmful algal blooms.<sup>13</sup> Projected increases in extreme precipitation events (Tables ES-1 and ES-2) combined with increases in impervious surfaces means that the risk of flooding in New Hampshire communities will continue to be a major concern. It remains difficult to provide a reliable quantitative estimate of the future health impacts (including deaths) from storms and floods in New Hampshire due to a variety of factors, including the absence of empirically documented flood-related deaths and injuries, which can be difficult to track. Despite this limitation, we estimate that the direct and indirect effects of flooding across New Hampshire are very likely to increase. We can also expect that some of the longer-term, indirect effects (such as stress and mental-health related impacts) are likely to be a significant issue in terms of both health care costs and morbidity.

### **Respiratory and Cardiovascular Illness (including asthma)**

Air pollution—in the form of ozone, particulate matter, sulfur dioxide, nitrogen oxides, and carbon monoxide—are harmful to human health and the environment. The most widespread health threats are posed by ground level ozone and particulate matter. Ambient levels of regulated air pollutants in New Hampshire have generally dropped since the mid-1970s, but air quality in many parts of the country falls short of health-based air quality standards.

In New Hampshire, the projected increase in summertime ozone,<sup>14</sup> as well as lengthening of the “summer” ozone season to include late spring and early fall, is likely to lead to more pollution-related cardiorespiratory illness and death in the state. The uncertainty regarding potential changes in fine-particle pollution due to climate change indicates more research is required before the public health impact can be quantified.

### **Allergies**

There is a considerable body of research on the impacts of climate change on aeroallergens and allergic respiratory diseases.<sup>15</sup> Because pollen can adversely influence health outcomes such as allergies and asthma, any increases in pollen associated with climate change could result in an increased burden of asthma and allergies. Increases in ozone projected to occur in a warmer climate can also lead to exacerbation of symptoms and increases in asthma cases.

We lack specific data to qualitatively or quantitatively assess the impact of climate change in New Hampshire over the past several decades on the length or intensity of the pollen season, on allergic reactions and asthma



episodes, or on lost work or school days related to allergies and asthma. Nonetheless, warmer temperatures, longer growing seasons (Tables ES1 and ES-2), and higher levels of CO<sub>2</sub> are expected to increase pollen production that will increase allergic reactions and asthma episodes in the future. Extreme rainfall and rising temperatures are also expected to increase the growth of fungi and molds, with resulting increases in respiratory and asthma related conditions. New Hampshire has a strong Asthma Coalition, which could be an important partner in preparing for and responding to these climate-related health impacts.

### **Vector-borne Disease**

Vector-borne disease incidence in New Hampshire has increased in the past decade,<sup>16</sup> and the projected increase in temperature and precipitation may create conditions conducive to further increases in incidence over time.<sup>17</sup> A recently released report by the White House<sup>18</sup> on the health impacts of climate change indicated that New Hampshire and Delaware experienced the greatest increase in reported cases of Lyme disease since 1991, followed by Maine, Vermont, and Massachusetts.

Without access to adequate temporal and spatial data, the ability to model complex relationships between climate and vector-borne disease incidence is limited. Currently, there is an increase in research that highlights the value of establishing baseline data (location and number of cases) for early detection of changes that may be related to climate change.<sup>19</sup> In New Hampshire, the combination of factors associated with the habitat of vectors and hosts is currently being investigated using complex systems models.<sup>20</sup> The research being performed as part of the NSF-funded New Hampshire Experimental Program to Stimulate Competitive Research (EPSCoR) program<sup>21</sup> may also help to support new areas of collaborative study in the future.

### **Foodborne Disease**

Foodborne illness is expected to increase as a result of extreme weather events associated with climate change. Nationally, the CDC estimates that approximately 16 percent of Americans (48 million people) become ill and 3,000 die of foodborne diseases every year.<sup>22</sup> In New Hampshire, the projected increase in temperature and precipitation (Tables ES-1 and ES-2) may be associated with increased power outages that disrupt refrigeration and food spoilage, and impacts to fisheries and other food economies associated with exposure to pathogenic organisms. As the link between foodborne illness and climate change is better understood, public health officials should be more prepared to manage these complex conditions.

There may be extensive agro-economic and human impacts linked to pathogens associated with the food industry. In New Hampshire, the common reportable foodborne illnesses are *Campylobacter* and *Salmonella*, which are associated with consumption of unpasteurized dairy products, contaminated water, poultry, and produce.<sup>23</sup> Illness from pathogenic vibrio species is also a concern and has been detected in the Great Bay Watershed since the 1970s; yet their persistence, distribution, and virulence as they relate to human health are not well understood.<sup>24</sup> As the link between foodborne infection and climate change becomes better understood, adaptation strategies for New Hampshire can be developed to decrease potential public health impacts.

## **Waterborne Disease**

Waterborne illness caused by microbial organisms may increase as a result of an increase in extreme weather events associated with climate change.<sup>25</sup> Increases in water temperature, precipitation frequency and severity, evaporation-transpiration rates, and changes in coastal ecosystem health could increase the incidence of water contamination with harmful pathogens, resulting in increased human exposure. At elevated surface water temperatures, evidence suggests that there may be an increased risk for infection with *Cryptosporidium* from water exposure.<sup>26</sup> People may also be increasingly exposed to pathogenic organisms as a result of recreational activities (e.g., swimming in contaminated water after an extreme precipitation event). This risk has implications for public health efforts to minimize beach closures and to improve food safety and sanitation.

Evidence suggests that waterborne diarrheal disease is sensitive to climate variability.<sup>27</sup> This may be particularly true in watersheds of New Hampshire, where commercial development and population increases have led to urbanization of natural coastal areas.

## **Health Behaviors and Chronic Disease**

Health behaviors such as diet, physical activity, and substance use are major modifiable risk factors of chronic disease, particularly for cardiovascular disease, stroke, diabetes, and some cancers. Vulnerabilities pertaining to health behaviors and chronic disease are likely to follow socio-demographic patterns similar to those for other health impacts, disproportionately affecting the elderly, socially or linguistically isolated individuals, immigrants/refugees, low income individuals, and those suffering from disabilities and/or multiple chronic illnesses.<sup>28</sup>

In New Hampshire, the projected increase in temperature and precipitation (Tables ES-1 and ES-2) may be directly associated with warmer seasons and extreme weather events that influence the ability of people with chronic disease to perform daily functions, engage in healthy behaviors such as physical activity, and respond to emergencies.

Although the relationship between chronic disease and climate change has received less attention in the literature compared to injuries and acute illnesses, climate change is likely to affect major chronic diseases in complex ways. Long-term conditions such as asthma and allergies have been covered in previous sections, and mental health will be covered in the next section. Climate change and severe weather can restrict the ability of persons with chronic disease populations to remain active, access medicine, participate in the workforce, or obtain healthy food. Physical activity and nutrition have direct impacts on obesity, diabetes, cardiovascular disease, some cancers, and certain mental health conditions.<sup>29</sup> One of the most exciting new research directions in climate change/public health collaborations is in the area of “co-benefits” related to many climate adaptation strategies (discussed in the ‘Next Steps’ section below).

## **Mental Health and Stress-Related Disorders**

Mental health is an important climate-related health impact in terms of identifying populations at risk, considering how to improve access to treatment, and address the costs of care. Poor mental health is associated with climate change and severe weather events. Some individuals with mental illness are especially susceptible to particular climate-related effects, such as heat stress.<sup>30</sup> Risk of suicide varies seasonally<sup>31</sup> and rises with hot weather,<sup>32</sup> suggesting potential climate impacts on depression. Research has demonstrated a link between high levels of anxiety and post-traumatic stress disorder among people affected by hurricanes, such as Katrina.<sup>33</sup> There is clear

evidence that the public health challenges arising in the wake of extreme weather events strain our already taxed health care systems.

The importance of a multi-sectoral strategy that integrates community- and family-based approaches must be recognized. Several existing initiatives in New Hampshire already embrace a family-centered philosophy for violence prevention and neighborhood health; connecting such efforts to climate adaptation could offer a powerful innovation.

### **Next Steps**

There is an unprecedented window of opportunity in terms of linking the co-benefits of multi-sectoral, multi-level planning initiatives currently being implemented in New Hampshire. Such multi-sectoral initiatives have the potential to move beyond a single-disease focus to promote multiple public health benefits, and to positively impact the spectrum of diseases highlighted in the CDC's BRACE framework.

We suggest considering the '**spectrum of prevention**'—primary, secondary, tertiary—as a useful lens through which to begin thinking about interventions to address the public health impacts of climate change. This lens can connect public health practice to other sectors (e.g., urban planning, land use and transportation planning, energy, integrated watershed resource management) which are critical partners in this effort. For example, there are valuable lessons to be learned from the interdisciplinary evidence-base on obesity prevention which emphasizes multi-sectoral partnerships and a policy, environment, and systems change approach.<sup>34</sup>

**Co-benefits** associated with primary/secondary prevention can minimize our vulnerability to almost all the diseases in the CDC BRACE framework, in contrast to interventions that address one at a time. This approach is supported by the Institute of Medicine, the Prevention Institute, and other notable public health organizations.

**Create a culture of resilience** using social networks. Because public health professionals cannot address the impacts of climate change alone, we suggest that efforts should be directed at intentionally building a supportive network of multi-sectoral partners who can support one another in developing a common understanding of the impacts, vulnerabilities, and opportunities for coordinated adaptation strategies at local, state, and regional scales. Examples could include integrating climate change adaptation elements into emergency preparedness plans, including health-related climate adaptation strategies into Master Plan revisions and zoning decisions, and partnering closely with the New Hampshire Department of Environmental Services' climate adaptation initiatives.<sup>35</sup> Valuable lessons can also be learned from other CDC Climate Ready States and Cities.<sup>36</sup> For example, Oregon provides a useful Health Impact Assessment toolkit for public health professionals on climate change and health impacts.<sup>37</sup>

## 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
<b>Minimum Temperature (°F)</b>							
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
<b>Maximum Temperature (°F)</b>							
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
<b>Temperature Extreme (days per year)</b>							
<32°F	164.0	-9.5	-10.9	-15.8	-25.5	-19.5	-43.9
<0°F	16.0	-7.0	-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
<b>Temperature Extreme (°F)</b>							
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
<b>Growing Season (days)</b>	162.0	11.1	12.0	17.0	28.6	20.4	48.7
<b>Precipitation (inches)</b>							
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
<b>Extreme Precipitation (events per year)</b>							
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
<b>Extreme Precipitation (events per decade)</b>							
4" in 48 hours	4.3	2.6	0.7	3.9	4.0	6.1	7.6
<b>Snow-Covered Days</b>	105	-9.6	-16.3	-15.0	-37.1	-23.7	-52.9

TABLE ES-1. 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 were 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.

## Northern 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
<b>Minimum Temperature (°F)</b>							
Annual TMIN	31.5	1.9	2.1	3.1	5.4	4.1	9.2
Winter TMIN	8.5	2.6	2.9	4.1	6.4	5.7	10.7
Spring TMIN	29.3	3.2	1.7	5.0	4.6	6.2	8.0
Summer TMIN	52.5	1.6	2.1	2.8	5.5	3.4	9.5
Fall TMIN	37.5	0.2	1.8	0.5	5.1	1.0	8.5
<b>Maximum Temperature (°F)</b>							
Annual TMAX	53.9	1.8	1.8	3.2	5.0	4.3	8.5
Winter TMAX	29.3	2.0	1.8	2.8	3.9	4.1	6.7
Spring TMAX	52.6	2.5	1.6	4.9	4.8	6.6	8.8
Summer TMAX	77.0	1.8	2.1	3.4	5.8	4.2	9.6
Fall TMAX	56.4	1.0	1.7	1.4	5.5	1.6	8.7
<b>Temperature Extreme (days per year)</b>							
<32°F	178.0	-9.7	-11.3	-16.5	-26.3	-20.2	-45.5
<0°F	28.0	-7.1	-7.0	-11.0	-15.8	-13.4	-21.2
>90°F	3.4	2.3	3.0	6.7	14.4	10.3	34.9
>95°F	0.4	0.3	0.6	1.2	3.6	2.3	12.5
<b>Temperature Extreme (°F)</b>							
TMAX on hottest day of year	90.8	1.7	1.5	2.8	4.9	4.1	8.8
TMIN on coldest day of year	-21.8	4.0	4.2	5.9	10.4	7.9	18.3
<b>Growing Season (days)</b>	150	9	11	18	29	21	50
<b>Precipitation (inches)</b>							
Annual mean	43.2	3.5	2.2	4.4	5.2	6.2	7.3
Winter mean	8.9	1.1	0.9	1.3	1.5	1.8	2.4
Spring mean	10.1	1.0	0.8	1.7	1.6	1.9	2.5
Summer mean	12.6	1.4	0.4	0.6	1.4	1.9	0.7
Fall mean	11.5	0.1	0.2	0.9	0.9	0.8	1.7
<b>Extreme Precipitation (events per year)</b>							
1" in 24 hrs	8.1	1.1	1.1	1.8	2.3	2.4	4.7
2" in 48 hours	2.8	1.3	1.3	0.3	2.4	1.4	4.9
<b>Extreme Precipitation (events per decade)</b>							
4" in 48 hours	2.5	1.9	1.2	1.9	3.0	4.0	6.3
<b>Snow-Covered Days</b>	144	-14.6	-5.0	-19.3	-21.1	-27.3	-42.2

TABLE ES-2. Climate grid with historical and projected future 30-year climatologies for temperature (15 stations) and precipitation (23 stations) variables averaged across northern New Hampshire (i.e., north of 43.75° north latitude). Daily meteorological data were 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 simula-

Health/Climate Indicator	Climate Change Indicator	Health Impact		Equity Considerations/Vulnerable Populations
		Primary	Secondary*	
Heat stress	Increase in number of hot days	Increase in heat related illness and death	Increase in cardio-vascular impacts; violence; suicide	Persons who: live in urban areas with little green-space (heat island effect); are vulnerable due to age (children, elders), socioeconomic status, race/ethnicity, comorbidities/pre-existing health conditions, social/linguistic isolation, or occupations; homelessness
Extreme weather	Increase in coastal and inland flooding	Physical injury & death; displacement, contaminated water supply; increase in mold	Lost work days; mental health impacts; increase water-borne disease	Same as for vulnerable populations under Heat Stress; also persons living in manufactured housing and flood-prone areas; emergency response personnel
	More severe ice storms	Physical injury & death; displacement	Loss of heating; CO poisoning; lost work days; increase food-borne disease	
Air Quality	More ozone events	Increase in pulmonary (including asthma) and cardio-vascular impacts; death	Reduced outdoor physical activity; lost work days	Persons with pre-existing asthma or other respiratory illnesses; other vulnerabilities as listed above
	Longer pollen season, higher pollen conc., more allergenic pollen	Increased allergies and allergic reactions	Lost work days, reduced physical activity	Persons with pre-existing allergies
Vector-borne disease	Warmer, wetter	Increased incidence of Lyme WNV, EEE and other emerging VB diseases	Chronic illnesses; reduced outdoor physical activity	Persons who work or play outside, especially without proper clothing.
Foodborne illnesses	Warmer air temperatures & more heat waves	Increase in spoiled food; Gastrointestinal illness	Dehydration; Increase in shellfish disease/closures	Same as for vulnerable populations listed under Heat Stress; particularly those who may have pre-existing issues with food access
Waterborne disease	Warmer water temperatures	Gastrointestinal illness (i.e., Giardiasis)	Dehydration; Increase in shellfish disease/closures; Red tide & cyanobacteria blooms	Same as for vulnerable populations listed under Heat Stress; people who frequently recreate outside
Health behavior & chronic disease	Integrated	Reduced outdoor physical activity; increased sedentary behavior and associated diseases (e.g., obesity, diabetes, Cardio-Vascular Disease)	Negative mental health impacts	Same as for vulnerable populations listed under Heat Stress
Mental Health	Integrated	Mental health	Negative impacts on other diseases and social impacts (e.g., violence) that can be associated with poor mental health	Vulnerable populations listed under “heat stress”; those with pre-existing substance abuse/mental health issues; those living where there are limited providers and treatment options (e.g., northern NH and rural areas).

\*Secondary impacts also include social & economic disruption, lost work days, & lost revenue

TABLE ES-3. Summary of potential health impacts associated with climate change organized using the CDC-BRACE framework

## I. BACKGROUND AND OBJECTIVES

A large and growing body of evidence has demonstrated that our changing climate is already causing adverse effects on human health.<sup>38</sup> Furthermore, it is expected that climate related health impacts will increase in both magnitude and frequency in the future.<sup>39</sup> This report provides an assessment of past and projected future climate change in New Hampshire, summarizes current knowledge on the health impacts of climate change, and outlines the potential climate-related human health impacts in New Hampshire in the coming decades. The primary objectives are to:

- present results of statistically downscaled global climate model simulations for specific locations across New Hampshire;
- review the evidence for health effects related to climate change, climate variability, and severe weather;
- inform adaptation strategies for New Hampshire, and relate the impacts to the Centers for Disease Control and Prevention (CDC) “Building Resilience Against Climate Effects” (BRACE) framework;<sup>40</sup>
- help identify the most vulnerable populations (e.g., children, elders, those living in poverty, people with underlying health conditions, and people living in certain geographic areas) who are at increased risk from climate-related health impacts; and

- fulfill a requirement to produce a written report on the results of a contract between the New Hampshire Department of Health and Human Services (DHHS) and UNH to assess climate vulnerabilities in relation to human health.

This report is partially based on a prior New Hampshire DHHS process in which more than fifty public health stakeholders from the public and private sectors met to assess the capacity and performance of New Hampshire’s public health system to prepare for and address climate-related health impacts. Using a structured, facilitated process recommended by the CDC - National Public Health Performance Standards Program, the participants engaged in candid dialogue and deliberation to assess the strengths, weaknesses, opportunities, and threats of the DHHS to address the health impacts of climate change in New Hampshire.

The next step in the planning process was for the NH DHHS - Division of Public Health Services (DPHS), together with the Department of Environmental Services (DES), to apply for a climate change and public health capacity building grant from the Association of State and Territorial Health Officials in June 2009. The main purpose of that proposal was to conduct a Needs Assessment, and using the results, begin the process of creating a strategic plan to prepare for and address the public health impacts of climate change

in New Hampshire. The proposal was funded, the Needs Assessment process initiated in February 2010, and a report summarizing the results of the Needs Assessment was published in May 2010.<sup>41</sup>

Using the Needs Assessment results, DPHS and DES immediately began the process of convening a Climate Change and Health Improvement Planning Committee to develop a Strategic Plan to prioritize and address the identified needs. The Committee met in June 2010. A key finding of the Needs Assessment was that while many public health monitoring, surveillance, planning, disease prevention, and preparedness systems are already in place that could be adapted to climate change preparedness, there was little or no coordinated focus on specific climate-related adaptive or preparedness interventions in New Hampshire.

To address this, in 2012, the state successfully applied for a grant through the CDC's Climate Ready States and Cities Initiative. Through this initiative, CDC is helping sixteen states and two cities develop ways to anticipate these health effects by applying climate science, predicting health impacts, and preparing flexible programs. CDC will help states and cities partner with local and national climate scientists to understand the potential climate changes in their areas.<sup>42</sup>

CDC's Building Resilience Against Climate Effects (BRACE) framework (see sidebar on pg 3) provides guidance to states and cities to develop strategies and programs to confront the health implications of climate change. In approaching the health implications of climate change it is important to find ways to understand and incorporate short-term weather predictions and longer range climate projections into public health planning and response activities. Coupling weather predictions and climate projections with epidemiologic analysis enables a jurisdiction to more effectively anticipate, prepare for, and respond to a range of climate sensitive health impacts.

During the development of this report, we identified several challenges that preclude further detailed

analysis of the relationship between climate change and disease burden in NH at this time. These include: (1) the fragmentation of existing data systems (e.g., "older" data [2000- 2009] reside in one system, and "newer" [2010-current] data in another); (2) non-aggregated data are not available at specific spatial or temporal resolutions; (3) reconciling HIPPA/privacy policies with the need for spatially/temporally specific data to aid in emergency response efforts; (4) data housed in different agencies (e.g., NH DES) and with different external institutions (e.g., UNH). We understand that DHHS is working to improve the utility of the NH Health WISDOM and NH Environmental Public Health Tracking databases.

This report serves to address Steps 1 and 2 in the BRACE framework for projecting climate vulnerabilities and related health burdens. It is our hope that this broad overview of climate and health combined with the New Hampshire specific information contained in this report provides local and regional stakeholders with decision relevant information. We also hope that this report and additional climate information (e.g., available on the Climate Solutions New England, NH EPSCoR Data Discovery Center and NH WISDOM websites<sup>43</sup>) serve as a foundation for the development of local climate change adaptation strategies that serve to build resilient communities and protect public health.



## II. FRAMEWORKS: MOVING FROM RISK TO RESILIENCE

A key component of the CDC's BRACE framework is building resilience. Resilience is a term that is used in many disciplines, with variations in meaning across disciplines. In public health, resilience is a measure of the ability of a community to utilize available resources to respond to, withstand, and recover from negative impacts.<sup>44</sup> More generally, people think of resilience as the ability to recover, persist, or thrive amid change.<sup>45</sup> The New Hampshire Climate and Health Workgroup has tentatively developed the following definition of resilience: ***Resilience is the ability and capacity to anticipate, prepare for, respond to, and recover from significant threats with minimum damage to human health and well-being, the economy, and the environment.***

Thus, as the BRACE framework provides an overarching call to build resilience, other frameworks are needed to help us better understand the multiple dimensions of the concept, and ultimately to move toward action. Frameworks describing the geography of risk are a good place to start, because both risk and resilience must be understood within the context of place and time. While there is a considerable interdisciplinary body of literature on the geography of risk (which provides a starting point for this report), we suggest that as New Hampshire develops its climate and health adaptation plan, a synergistic focus on the 'geography of resilience' should be nurtured. This means identifying where strengths exist, and how communities can build on

### FRAMEWORK: BUILDING RESILIENCE AGAINST CLIMATE EFFECTS (BRACE)

**Step 1:** Forecasting Climate Impacts and Assessing Vulnerabilities where a health department identifies the scope of the most likely climate impacts, the potential health outcomes associated with those climatic changes, & the populations and locations vulnerable to these health impacts within a jurisdiction.

**Step 2:** Projecting the Disease Burden where a health department, as best as possible estimates or quantifies the additional burden of health outcomes due to Climate Change – to support prioritization and decision making.

**Step 3:** Assessing Public Health Interventions where a health department seeks to identify the most suitable health interventions for the health impacts of greatest concern. The health impacts will have been quantified or better defined in the previous health risk assessment step.

**Step 4:** Developing and Implementing a Climate and Health Adaptation Plan where a health department develops and implements a health adaptation plan for climate change that addresses health impacts, gaps in critical public health functions/services, and a plan for enhancing adaptive capacity in the jurisdiction.

**Step 5:** Evaluating Impact and Improving Quality of Activities step for the Framework – whereby a health department can evaluate the processes it has used, determine the value of utilizing the framework and the value of climate and health activities undertaken. This step is also important for quality improvement and to incorporate refined inputs such as updated data or new information.

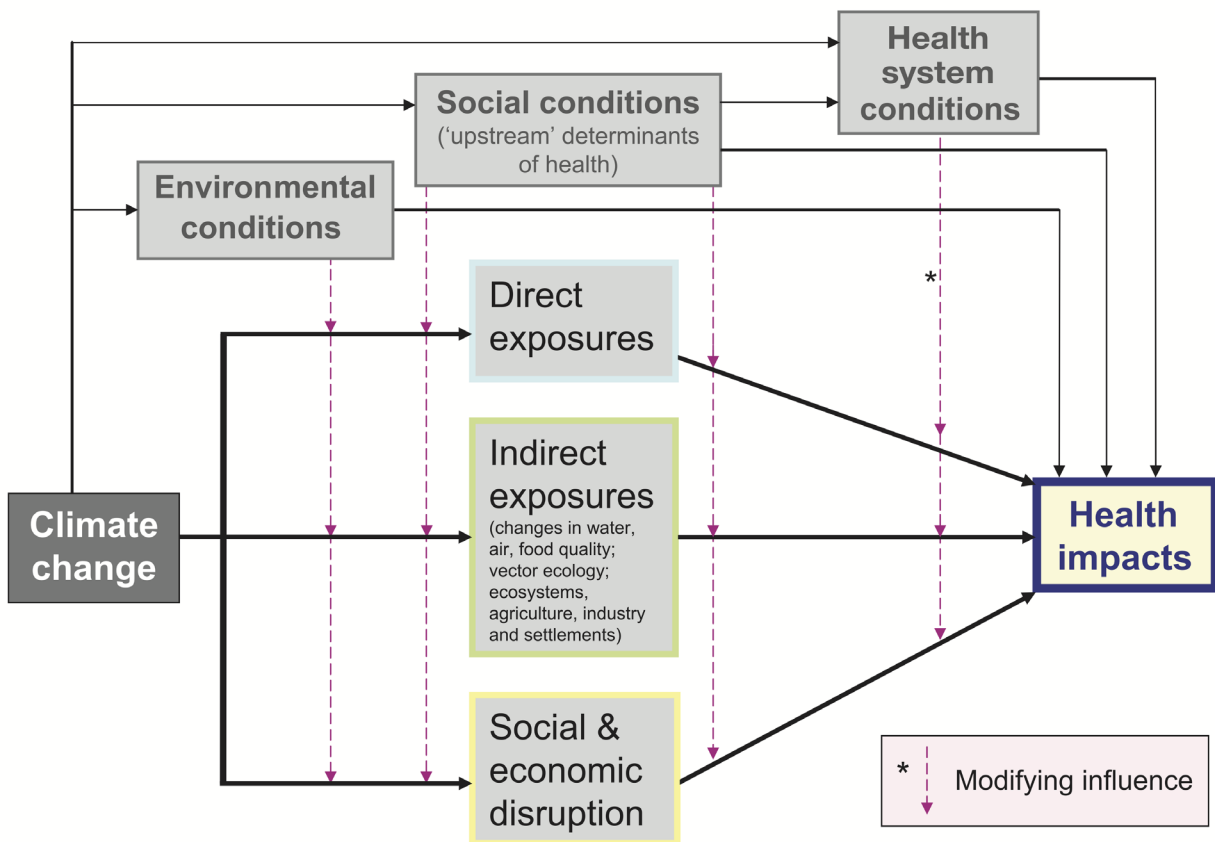
existing strengths.

## Geography of Risk Framework

Jerrett and colleagues<sup>46</sup> proposed an operational framework for communities to assess the health impacts of climate change and inequality that includes three underlying geographies: exposure, susceptibility, and adaptation. Their analytical framework hinged on four related concepts: (1) geography of susceptibility; (2) geography of exposure; (3) geography of adaptation, and (4) points of intersection among these three, which they refer to as the **geography of risk**. Each concept encompasses many factors, including environmental change, human activity patterns, behavioral changes in relation to perceived or real danger, and distributions of susceptible populations

and individuals. Because this framework lends itself to place-based adaptation strategies, it provides a useful starting point from which to begin dialogue on the impacts of climate change on human health in New Hampshire.

There are other useful frameworks that share aspects of the geography of risk approach described above. For example, the field of environmental health geography attempts to understand the overlap of two or more of the spheres of influence.<sup>47</sup> Additionally, the Intergovernmental Panel on Climate Change (IPCC) defines vulnerability to climate change as a function of a system's exposure, sensitivity, and adaptive capacity (Figure 1).<sup>48</sup> The Social Determinants of Health framework,<sup>49</sup> although not specifically focused on climate change, is emphasized in New Hampshire's



**FIGURE 1.** Schematic diagram of pathways by which climate change affects health, and concurrent direct-acting and modifying influences (environmental, social and health system factors) (Figure from IPCC 2007).<sup>54</sup>

State Health Improvement Plan (SHIP).<sup>50</sup> This framework calls attention to the structural causes of disease and health disparities (e.g., economic stability, education, neighborhood and built environment, discrimination, and institutional structures). Similarly, there is a growing movement to consider “Health in All Policies” that promotes inclusion of diverse perspectives in order to support more resilient community environments.<sup>51</sup>

The geography of risk concept and the IPCC climate change impacts and adaptation framework both arrive at essentially the same framework for demonstrating how human health impact is related to the physical, biological, behavioral, and sociopolitical dynamics of climate change. Each concept encompasses critical issues to vulnerable communities across space and time. Environmental health risk lies at the intersection of spheres of influence (i.e., changing temperatures and behavioral changes in relation to perceived risk). Both conceptual frameworks define vulnerability as a function of exposure, sensitivity, and adaptive capacity.

The conceptual frameworks have evolved to more specifically delineate health impacts associated with climate change, including both direct and indirect exposures to climate, modifications of environmental and societal conditions by climatic shifts, and feedback loops among these factors (e.g., Figure 1).

There has not yet been an extensive review of climate change adaptation success in the United States, particularly at local levels, since action is in the early stages.<sup>52</sup> According to the 2013 National Climate Assessment,<sup>53</sup> a successful adaptation approach to minimize health impacts includes defining the purpose and scope of a framework and its components early, but allowing for flexibility and refinement to take advantage of new opportunities. It also includes integrating the ecological and socioeconomic dimensions early by emphasizing the many ways that communities value their vulnerable resources.

There is a particular challenge in balancing the

needs of decision makers, who are often focused on the next year, or 5-10 years at the most, with the need to understand how climate change could impact health risks over decadal time frames or longer. Part of this challenge is considering how other factors are likely to change over time, such as demographics, urbanization, health care, and socioeconomic development. The more distant the time period, the more uncertain are changes in these and other factors. The choice of time periods will depend on the focus of the assessment. For example, if one goal of an assessment is to determine health-care infrastructure needs and vulnerabilities, then a longer time period would be of interest. The time period of the analyses will also depend on availability of model simulations of projected changes. Projecting possible health impacts associated with projected temperature and precipitation changes over longer time periods (i.e., middle to end of the century) should take into account changes in demographics and economic growth.

### III. CLIMATE CHANGE: FROM GLOBAL TO LOCAL<sup>55</sup>

#### 3.1 Background

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. Today, however, the story is noticeably different. Since the Industrial Revolution, atmospheric concentrations of heat-trapping gases, or greenhouse gases, such as carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O) have been rising as a result of increasing emissions from human activities.<sup>56</sup> The primary source of CO<sub>2</sub> derived from human activities originates from the burning of fossil fuels such as coal, oil, and natural gas. Carbon dioxide is also emitted to the atmosphere as a result of land use changes, including tropical deforestation. Agricultural activity and waste treatment are critical sources of CH<sub>4</sub> and N<sub>2</sub>O emissions. Methane derived from fossil fuel extraction and processing is now much larger than previous estimates.<sup>57</sup> 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<sup>58</sup>, 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 spatial 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.<sup>59</sup> 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.<sup>60</sup>

Furthermore, Earth's climate history, as read through the analysis of natural archives (e.g., ocean sediments, ice cores, tree rings), also reveals several "tipping points"; thresholds beyond which major and rapid changes occur when crossed and that lead to abrupt changes in the climate system.<sup>61</sup> 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

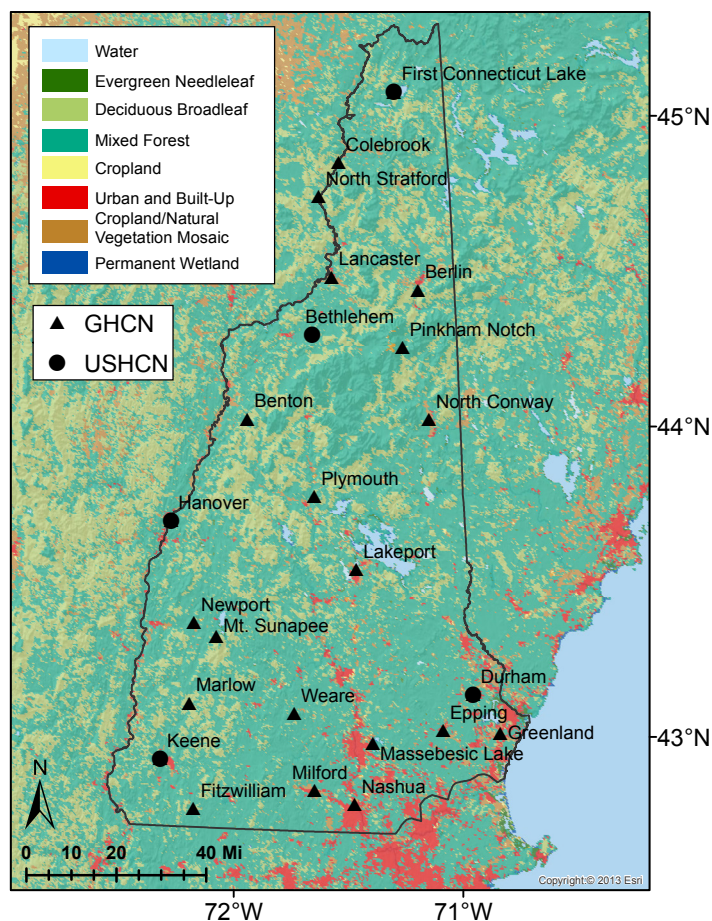
crossed has proven elusive.

Our local area of concern (New Hampshire) has already experienced an overall warming over the past century, with an increase in the rate of warming over the past four decades.<sup>62</sup> This change in our regional climate has been documented in a wide range of indicators that include an increase in temperature (especially in winter), overall precipitation, 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 (not just lilacs), longer growing seasons, and rising sea levels.

### 3.2 Historical Climate Change Across New Hampshire

Detailed information on how climate has changed across New Hampshire over the past century is provided in a series of recent climate assessments for the state.<sup>63</sup> Average monthly temperature and precipitation records from five long-term United States Historical Climatology Network (USHCN)<sup>64</sup> meteorological stations in New Hampshire (Bethlehem, Durham, First Connecticut Lake, Hanover, and Keene; Figure 2) provide a continuous record of temperature change for the last century in southern New Hampshire. Daily temperature records are available for several stations across New Hampshire back to 1960 from the Global Historical Climatology Network-Daily (GHCN- Daily).<sup>65</sup> 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 New Hampshire and assess the statistical significance of those trends are described in detail in the New Hampshire Climate Assessments.<sup>66</sup>

All five USHCN stations show that almost all annual and seasonal minimum and maximum temperatures



**FIGURE 2.** Map of New Hampshire showing land cover and the location of United States Historical Climatology Network (USHCN) stations (black dots) and Global Historical Climatology Network-Daily (GHCN) stations (black triangles). 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. Land cover data from 2011.

have been increasing across New Hampshire since 1895, and the rate of warming has increased over the past four decades (Table 1, next page). While the number of hot days has not changed much across New Hampshire since 1960, the number of cold days has decreased and temperature on the coldest day of the year has increased, reflecting the greater warming the region has experienced during the winter compared to summer. The length of the growing season has also lengthened by two to five weeks, depending on location.

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

Parameter	Keene		Durham		Hanover		Bethlehem		First Connecticut Lake	
	1985-2012	1970-2012	1985-2012	1970-2012	1985-2012	1970-2012	1985-2012	1970-2012	1985-2012	1970-2012
<b>TMAX (F per decade)</b>										
Annual	0.09	0.61	0.21	0.55	0.05	0.25	0.10	0.50	0.14	0.36
Winter	0.10	0.71	0.20	0.80	0.08	0.37	0.11	0.84	0.16	0.61
Spring	0.10	0.58	0.32	0.72	0.15	0.29	0.17	0.22	0.20	0.33
Summer	0.12	0.35	0.27	0.47	0.08	-0.05	0.11	0.15	0.09	0.04
Fall	0.04	0.68	0.11	0.48	-0.05	0.60	0.07	0.98	0.13	0.56
<b>TMIN (F per decade)</b>										
Annual	0.50	0.82	0.20	0.58	0.25	0.74	0.03	0.77	0.24	0.86
Winter	0.58	1.70	0.28	0.93	0.35	1.45	0.19	1.57	0.38	1.44
Spring	0.45	0.31	0.18	0.24	0.23	0.60	0.05	0.61	0.21	0.72
Summer	0.49	0.47	0.25	0.71	0.27	0.60	-0.04	0.32	0.19	0.50
Fall	0.50	1.11	0.14	0.83	0.22	0.61	0.00	0.78	0.24	0.95
<b>Growing Season (days per decade)</b>										
	NA	2.8	NA	10.0	NA	5.9	NA	4.0	NA	NA
<b>Precipitation (inches per decade)</b>										
Annual	0.32	2.02	0.56	1.63	0.26	1.16	0.39	0.68	-0.03	1.74
Winter	0.45	0.16	-0.03	-0.61	0.37	-0.11	0.14	-0.09	-0.05	0.03
Spring	0.21	0.14	0.08	0.20	0.20	0.22	0.02	-0.07	0.01	0.32
Summer	0.31	0.57	0.14	0.93	0.27	0.55	0.15	0.17	0.16	0.66
Fall	0.32	1.12	0.27	0.26	0.24	0.19	0.06	0.13	-0.05	0.52
Snowfall	NA	0.34	NA	-9.14	NA	-3.44	NA	-4.29	NA	-9.94
<b>Snow Cover (days per decade)</b>										
Winter	NA	0.0	NA	-6.6	NA	-2.9	NA	-0.4	NA	0.0
<i>*NA means no data available</i>										

**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 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.

than the long-term average. While overall increases in precipitation have been modest, the frequency of the most extreme precipitation events (4 inches in 48 hours) has increased at most locations across NH. And tidal gauge records show that relative sea level at Portsmouth, NH is rising at about 0.7 inches per decade over the past eight decades. This rate is essentially equivalent to the rate of global sea level rise over the past century.

From warmer winters to less snow cover to more heavy precipitation events to rising sea level, climate change is already impacting our lives, our health, our economy, and our ecosystems. The impacts are often most significant for communities that already face

economic or health-related challenges, and for species and habitats that are already facing other stressors. While some changes may bring potential benefits (such as longer growing seasons) many will be disruptive to society because our institutions and infrastructure have been designed for the relatively stable climate of the recent past, not the changing one of the present and future. Similarly, natural ecosystems will be challenged by changing conditions. Using information and building collaborations to prepare for these changes in advance provides economic opportunities, and proactively managing the risks will reduce costs in terms of human health, infrastructure, and natural resources over time.<sup>67</sup>

### 3.3 Future Climate Change Across New Hampshire

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.<sup>68</sup> 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 38 GHCN-Daily stations in New Hampshire and observed 24-hour cumulative precipitation for 61 GHCN-Daily stations in New Hampshire.<sup>69</sup> 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 the Appendix in the New Hampshire Climate Assessments.<sup>70</sup>

This section provides a broad overview of projected climate change for southern New Hampshire (meteorological stations located south of 43.90°N latitude; essentially south of the northern portion of Lake Winnepesaukee) and for northern New Hampshire (meteorological stations located north of 43.75°N latitude; essentially north of Lake Winnepesaukee) over the 21<sup>st</sup> Century depending on which global emissions scenario we follow: a high emissions (A1fi) or a low emissions (B1) scenario.<sup>71</sup> Basically, New Hampshire’s climate is projected to get warmer and wetter with the magnitude of change at the end of the century being greater under the higher emissions scenario.

More detailed indicators of potential future climate change (e.g., number of hot days per year, number of extreme precipitation events per decade, etc.) that

are closely related to a particular health impact(s) are presented and discussed with the relevant health impact in Chapter 4. For a complete overview of NH climatologies (past and future), Appendix A provides a set of climate grids that summarize the entire range of climate change indicators (temperature, precipitation, extremes, growing season) for 38 locations across New Hampshire that contain both temperature and precipitation records. The climate grids are organized

#### MAPPING PAST AND FUTURE CLIMATE CHANGE ACROSS NEW HAMPSHIRE

This report details many of the projected changes in climate across New Hampshire under a higher versus a lower future scenario. Additional detailed information is provided in the climate grids (Appendix A), which contain historical and projected future 30-year climatologies for 38 Global Historical Climatology Network- Daily (GHCN-Daily) meteorological stations across New Hampshire for the historical period (1980–2009) and the future (near-term [2010–2039], medium-term [2040–2069], and long-term [2070–2099]). The climate grids are organized by New Hampshire Health Service Areas.

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 number of snow-covered days. In addition, maps for the state of New Hampshire for all twenty-five climate indicators listed in Tables 2 and 3 (pg 26, 27) 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 (NH- EPSCoR)—Data Discovery Center.

by New Hampshire Health Service Areas. In addition, projections of temperature and precipitation in New Hampshire discussed in the report and presented in the climate grids in Appendix A can also be mapped online at the New Hampshire Experimental Program to Stimulate Competitive Research (NH EPSCoR) - [Data Discovery Center](#).<sup>72</sup>

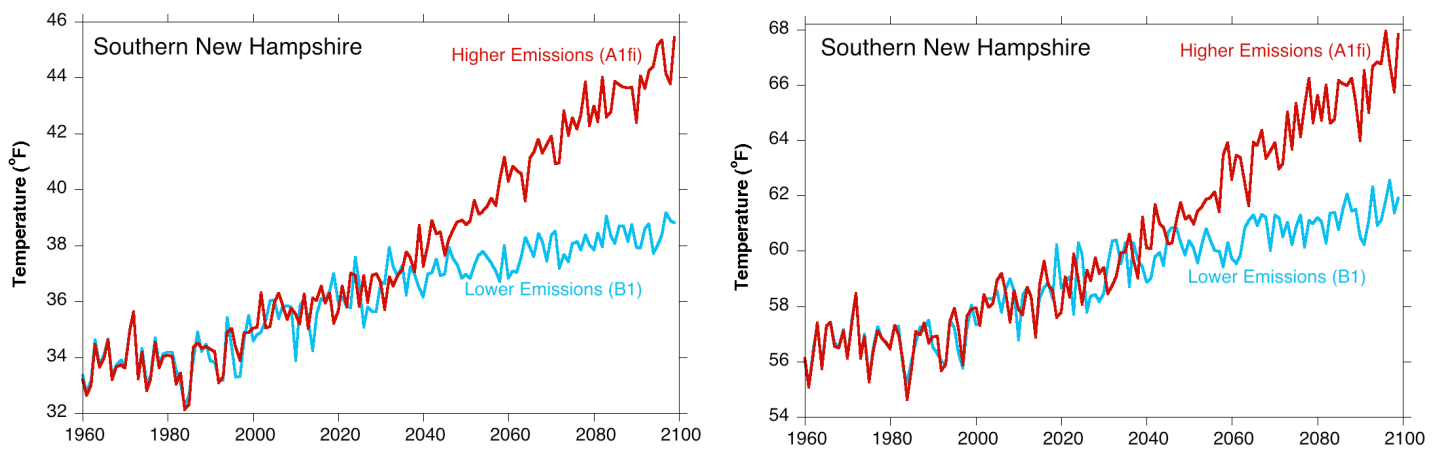
### Temperature

As a result of an increase in heat-trapping gases in the atmosphere, temperatures across New Hampshire will continue to rise regardless of whether the future follows a lower or higher emissions scenario. However, it is clear that the magnitude of warming that can be expected will depend on which emissions pathway is followed (Figure 3 and 4; Tables 2 and 3). During the first part of the 21<sup>st</sup> century (2010-2039), annual temperature increases are similar for the lower (B1) and higher (A1fi) emissions scenarios for maximum and minimum annual and seasonal temperatures. The magnitude of warming begins to diverge during the

middle part of the century (2040-2069), with the higher emissions scenario resulting in warming that diverges from warming projected from the lower emissions scenario. Temperature increases under the higher emissions scenario will be nearly twice that expected under the lower emissions scenario by the end of the 21<sup>st</sup> century. Overall, NH can expect to see increases in annual maximum and minimum temperature ranging from +4°F to +11°F by 2070-2099 (Table 2).

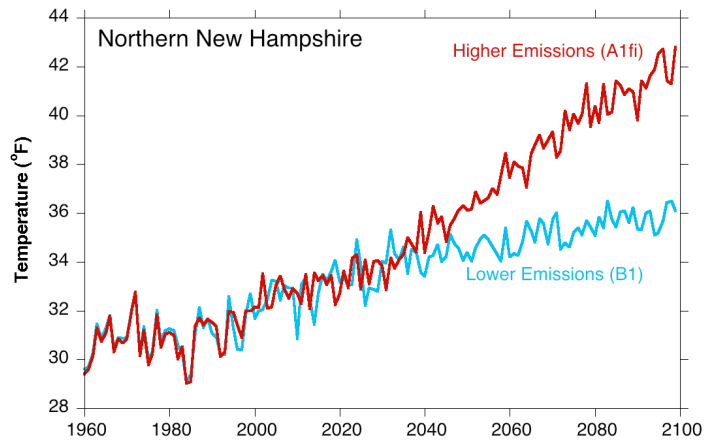
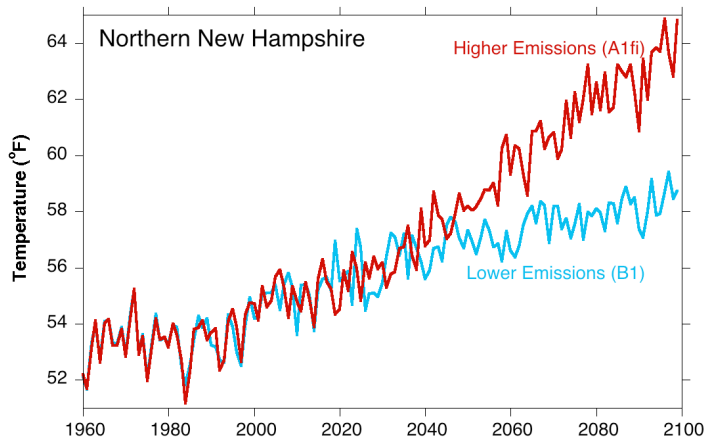
### Precipitation

Annual precipitation across New Hampshire is expected to increase by 15-20% by the end of the 21<sup>st</sup> century under both emission scenarios (Figure 5 and 6). Slightly higher increases are expected under the higher versus the lower emission scenarios in both southern and northern NH (Tables 2 and 3). The increase in precipitation is expected to be greatest in the winter and spring, with intermediate increases in the summer, and the lowest increases during the fall.

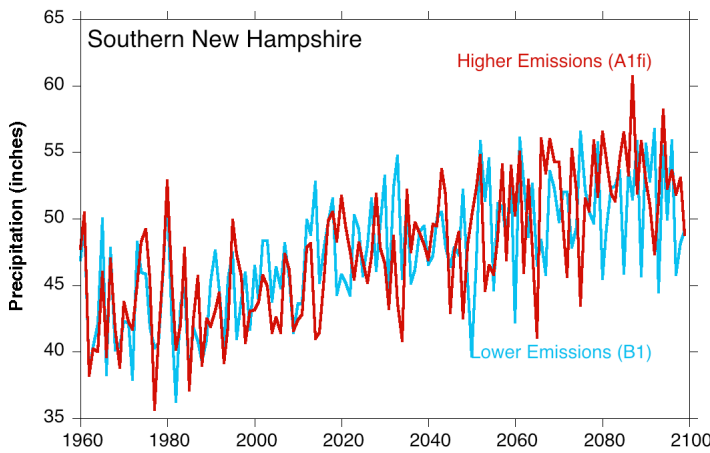


**FIGURE 3.** Average annual maximum temperatures (top) and minimum temperatures (bottom) for southern New Hampshire averaged over 21 sites from the higher emission scenario (A1fi; red line) and lower emission scenarios (B1, blue line), 1960-2099.

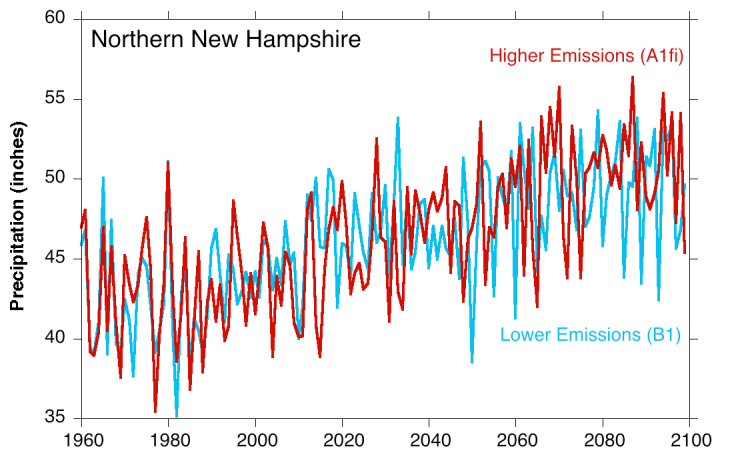




**FIGURE 4.** Average annual maximum temperatures (top) and minimum temperatures (bottom) for northern New Hampshire averaged over 15 sites from the higher emission scenario (A1fi; red line) and lower emission scenarios (B1, blue line) 1960-2099.



**FIGURE 5.** Average annual precipitation for southern New Hampshire (i.e., south of 43.9° north latitude) averaged over 41 sites from the higher emission scenario (A1fi; red line) and lower emission scenarios (B1, blue line), 1960-2099.



**FIGURE 6.** Average annual precipitation for northern New Hampshire (i.e., north of 43.75° north latitude) averaged over 23 sites from the higher emission scenario (A1fi; red line) and lower emission scenarios (B1, blue line), 1960-2099.

## 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
<b>Minimum Temperature (°F)</b>							
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
<b>Maximum Temperature (°F)</b>							
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
<b>Temperature Extreme (days per year)</b>							
<32°F	164.0	-9.5	-10.9	-15.8	-25.5	-19.5	-43.9
<0°F	16.0	-7.0	-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
<b>Temperature Extreme (°F)</b>							
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
<b>Growing Season (days)</b>	162.0	11.1	12.0	17.0	28.6	20.4	48.7
<b>Precipitation (inches)</b>							
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
<b>Extreme Precipitation (events per year)</b>							
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
<b>Extreme Precipitation (events per decade)</b>							
4" in 48 hours	4.3	2.6	0.7	3.9	4.0	6.1	7.6
<b>Snow-Covered Days</b>	105	-9.6	-16.3	-15.0	-37.1	-23.7	-52.9

TABLE 2. Past and projected future 30-year climatologies for temperature and precipitation variables averaged for 25 stations in southern NH (i.e., south of 43.9° north latitude). Daily meteorological data was not available for all sites, so the historical values (1980-2009) in these tables were derived from the downscaled GCM model output

## Northern 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
<b>Minimum Temperature (°F)</b>							
Annual TMIN	31.5	1.9	2.1	3.1	5.4	4.1	9.2
Winter TMIN	8.5	2.6	2.9	4.1	6.4	5.7	10.7
Spring TMIN	29.3	3.2	1.7	5.0	4.6	6.2	8.0
Summer TMIN	52.5	1.6	2.1	2.8	5.5	3.4	9.5
Fall TMIN	37.5	0.2	1.8	0.5	5.1	1.0	8.5
<b>Maximum Temperature (°F)</b>							
Annual TMAX	53.9	1.8	1.8	3.2	5.0	4.3	8.5
Winter TMAX	29.3	2.0	1.8	2.8	3.9	4.1	6.7
Spring TMAX	52.6	2.5	1.6	4.9	4.8	6.6	8.8
Summer TMAX	77.0	1.8	2.1	3.4	5.8	4.2	9.6
Fall TMAX	56.4	1.0	1.7	1.4	5.5	1.6	8.7
<b>Temperature Extreme (days per year)</b>							
<32°F	178.0	-9.7	-11.3	-16.5	-26.3	-20.2	-45.5
<0°F	28.0	-7.1	-7.0	-11.0	-15.8	-13.4	-21.2
>90°F	3.4	2.3	3.0	6.7	14.4	10.3	34.9
>95°F	0.4	0.3	0.6	1.2	3.6	2.3	12.5
<b>Temperature Extreme (°F)</b>							
TMAX on hottest day of year	90.8	1.7	1.5	2.8	4.9	4.1	8.8
TMIN on coldest day of year	-21.8	4.0	4.2	5.9	10.4	7.9	18.3
<b>Growing Season (days)</b>	150	9	11	18	29	21	50
<b>Precipitation (inches)</b>							
Annual mean	43.2	3.5	2.2	4.4	5.2	6.2	7.3
Winter mean	8.9	1.1	0.9	1.3	1.5	1.8	2.4
Spring mean	10.1	1.0	0.8	1.7	1.6	1.9	2.5
Summer mean	12.6	1.4	0.4	0.6	1.4	1.9	0.7
Fall mean	11.5	0.1	0.2	0.9	0.9	0.8	1.7
<b>Extreme Precipitation (events per year)</b>							
1" in 24 hrs	8.1	1.1	1.1	1.8	2.3	2.4	4.7
2" in 48 hours	2.8	1.3	1.3	0.3	2.4	1.4	4.9
<b>Extreme Precipitation (events per decade)</b>							
4" in 48 hours	2.5	1.9	1.2	1.9	3.0	4.0	6.3
<b>Snow-Covered Days</b>	144	-14.6	-5.0	-19.3	-21.1	-27.3	-42.2

**TABLE 3.** Past and projected future 30 year climatologies for temperature and precipitation variables averaged for 15 stations in northern NH (i.e., north of 43.75° north latitude). Daily meteorological data was not available for all sites, so the historical values (1980-2009) in these tables were derived from the downscaled GCM model output.

## IV. CLIMATE IMPACTS ON HEALTH

Changes in climate, including changes in the frequency, intensity, and average temperature, precipitation, and wind patterns result in a variety of impacts including extreme weather, effects on ecosystems, sea level rise, and environmental degradation that lead to direct and indirect negative human health effects.

Chapter Three provided an overview of projected climate change across New Hampshire depending on which global emissions scenario the world follows (Step 1 in the CDC BRACE Framework: projecting climate impacts). This chapter provides a review of the extensive published literature on the impacts of climate change on human health and, where possible, estimates the additional disease burden associated with climate change (Step 2 in the CDC BRACE framework). The chapter is organized based on the CDC<sup>73</sup> framework into the following sections:

- Temperature, heat events and heat stress injury/death
- Extreme weather and injury/death
- Temperature, air quality, and respiratory and cardiovascular illness
- Pollen, mold, and allergies
- Temperature, precipitation, and vector-borne diseases
- Temperature, precipitation, severe weather, and foodborne diseases
- Temperature, precipitation, and waterborne diseases
- Climate change, health behaviors and chronic disease
- Climate change, mental health, and stress-related disorders

Each section provides: (1) a summary of existing knowledge on the public health impacts of climate change based on a review of the peer-reviewed published literature, beginning with global and national studies and then moving onto more regional/local studies; (2) an assessment of potential future climate change across New Hampshire of relevance to the public health issue(s) addressed in the section; and (3) an assessment of the impact of projected climate change across New Hampshire on the public health issue(s) addressed in the section.

### 4.1 Heat Stress

Increased heat-related morbidity and mortality is projected to be one of the most significant impacts of climate change on human health, and the northeast United States is likely to be particularly vulnerable.<sup>74</sup> According to the Centers for Disease Control,<sup>75</sup> heat-related morbidity is characterized by conditions such as heat stroke, which is the most serious type of heat stress or heat-related disorder. Heat stroke can cause death or permanent disability, and can manifest in

various clinical outcomes. People with chronic health problems (e.g., cardiovascular disease, diabetes, obesity) are more susceptible to the effects of heat stress compared to otherwise healthy individuals.

#### 4.1.1 Summary of Existing Knowledge

Research on the impacts of high daily temperatures and heat waves on human health is extensive, and has gained importance in recent decades. International studies have documented the association of heat waves and temperature extremes with human mortalities.<sup>76</sup> Heat waves are associated with hospital admissions for cardiovascular, kidney, and respiratory disorders.<sup>77</sup> Unable to restore a normal temperature, organs can shut down, contributing to death from heat stroke. Other heat-related ailments include heat exhaustion, heat cramps, sunburn, and heat rashes.

Internationally, there have been a series of studies evaluating heat related deaths in response to high temperatures.<sup>78</sup> In August 2003, the European heat wave contributed to an estimated 14,800 deaths with average temperatures 6°F above normal. Further studies have linked the observed higher frequency of heat waves in Europe to human influence on the climate system.<sup>79</sup>

A 1995 summer heat wave in London was associated with a 16% increase in mortality.<sup>80</sup> In 1987 and 1988, a heat wave in Athens, Greece was associated with 500 to 1,000 estimated deaths.<sup>81</sup> Air quality and heat stress conditions often combine to contribute to a high death rate during these events.<sup>82</sup>

Daily mortality from extreme heat events in regions of England and Wales between 1993 and 2003 showed that a risk of mortality was observed for heat and cold exposure.<sup>83</sup> The strongest 'heat effects' were reported in London and strongest 'cold effects' in the Eastern region of the United Kingdom. Elderly people, especially those in nursing home facilities, were most vulnerable.

Studies in the US have found that extreme

temperatures are associated with an increased risk of illness and death.<sup>84</sup> In the US, extreme heat may have a greater impact on human health,<sup>85</sup> especially among the elderly.<sup>86</sup>

Fowler et al. reported that 7,233 heat-related deaths (an average of 658 per year) occurred during the period 1999–2009 in the United States.<sup>87</sup> This same study also examined reports of deaths from city-specific extreme heat events (EHE) that occurred in the US during the previous 20-year period. In 2012, heat events in New York City caused a lower fatality rate than expected (0.11 deaths per 100,000) compared to previous EHEs of similar duration. Although it is possible that public health interventions such as heat warning systems are having a positive effect, evidence to support such an assertion is currently limited.

Studies of heat waves in large US cities show an association between the number of deaths and increases in heat.<sup>88</sup> For example, after a 5-day Chicago heat wave in 1995 in which maximum temperatures in the city ranged from 93 to 104°F, the number of deaths increased 85% over the number recorded during the same period of the preceding year.<sup>89</sup> At least 700 deaths beyond those expected for that period in that population were recorded and most were attributed to heat stress.<sup>90</sup> Projection of the health impacts due to future climate change suggests that heat waves in Chicago and Paris will be 25% and 31% more frequent, respectively, by 2090 and that the average length of a heat wave in Paris may increase from 8-13 days to 11-17 days.<sup>91</sup>

Increases in death rates following heat wave deaths result not only from heat stroke and related conditions,<sup>92</sup> but also from cardiovascular disease, respiratory disease, and cerebrovascular disease.<sup>93</sup> Recent analysis suggests that high ambient temperatures are a risk factor for kidney stones, although precise relationship between high temperatures and kidney stone presentation remains uncertain.<sup>94</sup>

There are several methods for estimating the public health threat and impact of EHEs. Since these methods can have a significant impact on the resulting estimate, it is important to recognize their differences when reviewing information describing the public health burden of EHEs<sup>95</sup>. Conservative estimates of EHE mortality counts cases in which exposure to excessive heat is reported on a death certificate as a primary or contributing factor.

Reid and others claimed that although all large metropolitan areas will likely have much higher numbers of deaths due to prolonged heat waves,<sup>96</sup> rural areas may show higher relative percentage increases. However, more research is needed on how residents in urban versus rural settings may adapt differently. The risk factors in the Reid study are relevant to the discussion of the health impacts of climate change in NH because of several demographic trends: 1) an aging population, which will include greater prevalence of chronic disease and disability; 2) an increasingly diverse population in cities like Manchester and Nashua; 3) increasing urbanization and population growth especially along the seacoast, with corresponding increases in impervious surfaces and vehicle traffic; 4) aging infrastructure and housing, especially in areas where socio-demographic vulnerability is clustered.

The Northeast US has been impacted by several recent extreme heat events. For example, surface temperatures in New York City's urban areas on a summer's day are strongly influenced by the heat-island effect, with temperatures 10°F higher than the forested parts of Central Park.<sup>97</sup> This same study conducted an analysis for New York City that compared the maximum heat index with different indicators to predict daily variation in warm-season natural-cause mortality from 1997 through 2006. Using time-series models to estimate weather-mortality relationships, the results suggest that same-day maximum heat index was linearly related to mortality risk.

During June 30–July 13, 2012, intense thunderstorms

in the northeast and mid-Atlantic region caused widespread damage and power outages. Extreme heat with maximum temperatures exceeding 100°F was experienced. Thirty-two heat-related deaths (0.11 deaths per 100,000 populations) were reported in four states (Maryland, Ohio, Virginia, West Virginia), during the two weeks following the storms. The median age of the decedents was 65 years, and most of the excessive heat exposures occurred within the decedents' homes. Vulnerability to extreme heat events is influenced by many factors, including outdoor and indoor air temperatures, air quality, baseline health status and comorbidities, age, access to air conditioning, and socioeconomic factors.<sup>98</sup>

In addition to heat-related mortality, increased health-related morbidity and costs, such as increased hospitalizations are predicted in the Northeast's major metropolitan areas.<sup>99</sup> Researchers recommend that city-specific analyses should be conducted to more accurately assess the public health risks associated with extreme heat events.

Research suggests that the urban core of cities in the Northeast experience higher temperatures than surrounding rural areas.<sup>100</sup> However, vulnerability to heat may become a major issue in rural areas and small towns, due mainly to the fact that air conditioning is less prevalent in parts of the rural Northeast where heat waves have historically been rare.<sup>101</sup> Heat-related mortality is a growing public health concern as demographic shifts in New England make the region particularly vulnerable.<sup>102</sup>

#### **4.1.2 Climate Change in New Hampshire: Extreme Heat Events**

Increases in extreme heat events in the future across New Hampshire 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. The results of the downscaled global climate model simulations are summarized for four

30-year periods: (1) historical, 1980-2099, (2) early century, 2010-2039, (3) mid-century, 2040-2069, and (4) late-century, 2070-2099 for southern and northern New Hampshire in Table 2 and 3 (respectively) and in the individual town and city climate grids provided in Appendix A.

**Days above 90°F**

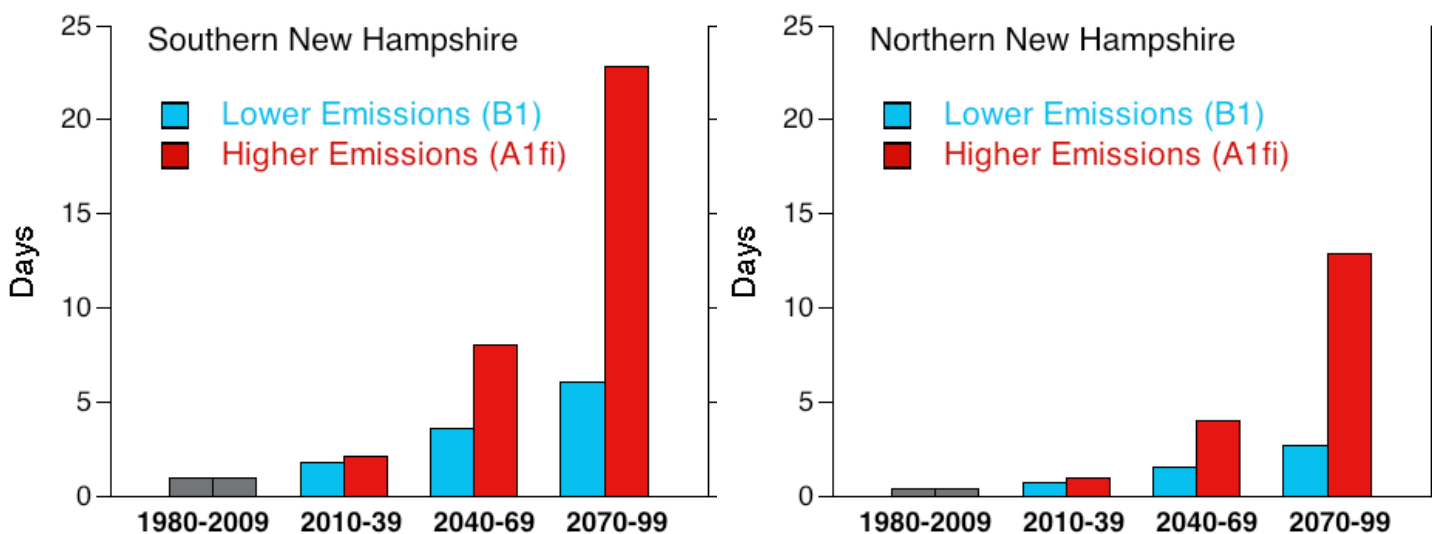
During the historical baseline period 1980-2009, southern NH experienced, on average, seven days per year above 90°F each year, with more hot days at sites in far southern New Hampshire (e.g., Keene, Manchester, and Nashua). By the middle of the century (2040-2069), southern NH can expect to experience on average between 18 and 28 days above 90°F (under the lower and higher emissions scenarios, respectively), which represents a two- to four-fold increase compared to the historical period. By 2070-2099, southern NH on average can expect 23 days per year with daytime maximum temperatures above 90°F under the lower emissions scenario and over 54 days per year under the higher emissions scenario, about four to eight times the historical average. Under the high emissions scenario, Manchester would experience over 70 days per summer with temperatures above 90°F, essentially making the summer a prolonged heat

wave punctuated by slightly less uncomfortable days.

During the historical baseline period 1970-1999, northern NH experienced, on average, 3 days per year above 90°F each year. By the middle of the century, northern NH can expect to experience on average between 10 and 18 days above 90°F (under the lower and higher emissions scenarios, respectively), which represents a three- to six-fold increase compared to the historical period. By 2070-2099, northern NH on average can expect 14 days per year with daytime maximum temperatures above 90°F under the lower emissions scenario and over 38 days per year under the higher emissions scenario, about five to twelve times great that the historical average.

**Days above 95°F**

From 1980-2009 extreme daytime maximum temperatures above 95°F were historically rare across southern NH, occurring on average one day per year (Table 2; Figure 7). By the middle of the century, this is projected to increase three- to seven-fold. By the end of the century and under the lower emissions scenario, southern NH can expect to experience six days per year above 95°F; under the higher emissions scenario, the number of days above 95°F is expected to increase to 22 days, more than 20 times the historical average.



**FIGURE 7.** Average number of days above 95°F per year, historical (grey) and projected lower emissions (blue) and higher emissions (red), shown as 30-year averages for northern NH (top) and southern NH (bottom). Projected values represent the average of four AOGCM simulations.

For northern NH during the historical period, extreme daytime maximum temperatures above 95°F were extremely rare (Table 3, Figure 7). By the middle of the century, this is projected to increase four- to ten-fold. By the end of the century and under the lower emissions scenario, northern NH can expect to experience on average three days per year above 95°F; under the higher emissions scenario, the number of days above 95°F is expected to increase to 13 days, more than 30 times the historical average.

#### ***Projected Temperature on the Hottest Day of the Year***

As the number of extremely hot days per year increases, the daytime maximum temperature on the hottest day of the year is also expected to increase (Tables 2 and 3, pg 26, 27). By the middle of the century, the temperature on the hottest day of the year is projected to increase, on average, by 3 to 5°F for both southern and northern NH. By the 2070-2099, the temperature on the hottest day of the year is projected to increase by 4 to 9°F across New Hampshire. Under the higher emissions scenario, the average maximum temperature over a 30 year period (2070-2099) is projected to be 102°F in southern NH.

#### **4.1.3 Potential Public Health Impact in New Hampshire: Extreme Heat Events**

The projected increase in the number of hot days and temperature on hottest day of the year will likely be associated with more heat stress among people, more heat injuries, and deaths. Future increases in the frequency and intensity of heat waves are likely to have a greater impact on persons living in old or poorly insulated houses, which offer less protection from the outside heat,<sup>103</sup> and those living without air conditioners. Population aging may further amplify vulnerability; the elderly and those with pre-existing disease are often more susceptible to heat. Urban planning decisions that create areas with little vegetation or green space show the most profound

relationships to negative heat-related health impacts, more than double the risk related to typical social vulnerability indices. Also important is the interaction between social and environmental vulnerabilities (e.g., low income, elderly persons often live alone in dense inner city environments, as was the case in the Chicago heat wave).

Managing the health effects of temperature in response to climate change is an emerging public health challenge in New Hampshire. While urban areas in New Hampshire are likely to be relatively hotter in the future compared to rural areas (based on the heat island effect), previous research has shown that rural areas (and much of New England can be classified as rural) can be more vulnerable to heat associated diseases.<sup>104</sup> The exposures most likely to be associated with heat related health risks across New England are factors such as a lack of air-conditioning, lower socio-economic status, socially isolated individuals, individuals living in dense inner city areas with little vegetation/green space, and a higher percentage of elderly and those with pre-existing chronic disease.

In New Hampshire, the proportion of residents living in urban areas is projected to increase and this will complicate the vulnerability of certain populations as climate changes. A larger number of people living in urban areas may contribute to additional heat-related health problems because of urban heat islands, an interaction between air pollution and heat, and higher concentrations of heat-susceptible people.<sup>105</sup>

Although urban heat islands may increase the vulnerability of urban populations to heat-related health impacts in the future,<sup>106</sup> the urban heat island effect is not always accounted for in assessments of heat stress. This effect could be addressed by using surface temperature derived from remote sensing data. Using more accurate satellite data to create models of the land surface temperature at higher resolution will allow for heat stress impacts to be measured depicting small-scale variations in the urban heat island.



There are limitations to estimating the magnitude of temperature-related mortality resulting from a warming climate.<sup>107</sup> For example, the primary cause of extreme heat related deaths is not necessarily documented on the death certificate. More work is needed to collect and summarize useful medical information on the health impacts as well as improved surveillance systems that allow for data extraction at appropriate spatial (county or smaller) and temporal (i.e., daily) scales.

Although qualitative and quantitative studies have outlined areas of concern and offer reasonable predictions, there is a need to improve our understanding using integrated systems modeling of heat-related health impacts under various climate change scenarios.

The State of New Hampshire has developed and implemented an Excessive Heat Action Plan, and continues to update its contents as needed.<sup>108</sup> Elements of the plan include working with the National Weather Service to forecast high-risk heat events, communicating with local officials and the public, opening the State emergency operations center if needed, and working with local emergency preparedness staff to identify cooling centers. One of the key DHHS activities is to track real-time data from hospitals to determine if heat injury admissions are increasing and if vulnerable populations are being affected. Local authorities can then make the final decision to open and maintain a cooling center. In addition, DHHS has worked with the NH Interscholastic Athletic Association (NHIAA) to educate school officials and coaches about the triple threats of physical activity, high temperatures, and poor air quality during late summertime heat events. Many studies have linked temperature to health risk, with non-linear J- or U-shaped relationships exhibiting increased risk of mortality at both extremely high and extremely low temperatures.<sup>109</sup>

In New Hampshire, the projected increase in the

frequency of hot days and associated increase in heat stress will likely lead to more heat injuries and deaths. Based on the assumption that the mortality rate is related to the projected increase in the number of days where maximum temperature is greater than 95°F and using the conservative 2012 New York City base rate of 0.11 deaths per 100,000, the fatality rate could increase an order of magnitude or more across New Hampshire by the end of the century under the high emissions scenario. Based on the assumption that heat-related hospital discharge rates are directly related to the increase in the number of days where maximum temperature is greater than 95°F, we also expect that heat-related hospital discharges per 100,000 could rise an order of magnitude or more across New Hampshire by the end of the century under the high emissions scenario.

The preplanned heat response activities that were associated with the lower fatality rate observed in New York in 2012 underscores the importance of implementing similar prevention strategies. Also note that these estimates also do not account for shifts in socio-demographic vulnerabilities (e.g., aging population, higher rates of baseline disease).

## 4.2 Extreme Weather

Extreme weather - from extreme precipitation events to nor'easters to floods to ice storms to windstorms to hurricanes to tornadoes to wildfires to drought - impact infrastructure, ecosystems, society, and human health in a variety of ways. Worldwide, the increase in the impact of severe weather on society and human health is troubling.<sup>110</sup> In the United States, overall and insured losses from meteorological, hydrological, and climatological events have quadrupled since 1980, with the largest losses occurring in the aftermath of Hurricane Katrina (2005; close to \$200 billion US) and Superstorm Sandy (2012; about \$115 billion US).<sup>111</sup>

#### 4.2.1. Summary of Existing Knowledge

##### *Extreme Precipitation, Storms, and Floods*

Many of the human health impacts resulting from extreme weather events are related to storms that cause large precipitation events that increase the risk of flooding and erosion. Floods are among the most common natural disaster and the leading cause of natural disaster fatalities worldwide.<sup>112</sup> For example in China in 2003, an estimated 130 million people were adversely impacted by floods.<sup>113</sup> A comprehensive review found that thousands died from storms followed by floods and landslides in Venezuela and Mozambique.<sup>114</sup>

Extreme precipitation events negatively impact human health in several ways; both direct and indirect (Figure 8). Direct health impacts include physical injuries and, in some cases, death (including drowning in floods) and structural collapse of buildings and other infrastructure. As with heat waves, the people most at risk include young children, older adults, people with pre-existing conditions, and the poor. Sea level rise increases the health risks associated with flooding due

to coastal storms (hurricanes, typhoons, nor'easters), threatening critical infrastructure, polluting water supplies, and worsening immediate and chronic health effects. Indirect effects outnumber the direct effects and likely will be more costly to communities, and include degradation of water quality from contamination of drinking water supplies.<sup>115</sup>

A review of literature including the World Health Organization (WHO) has provided frequency of event data by deaths and number affected globally.<sup>116</sup> One of the challenges of disaster statistics is to determine if the increase in events and human impact are associated with poverty, poor housing, and building in areas at risk (deltas, flood plains, mountain sides, etc.) or a true increase in the number or severity of severe weather events.

In addition to mortality, morbidity associated with extreme weather and flooding include:

- physical injury;
- increases in respiratory and diarrheal diseases because of crowding of survivors, often with limited shelter and access to potable water;

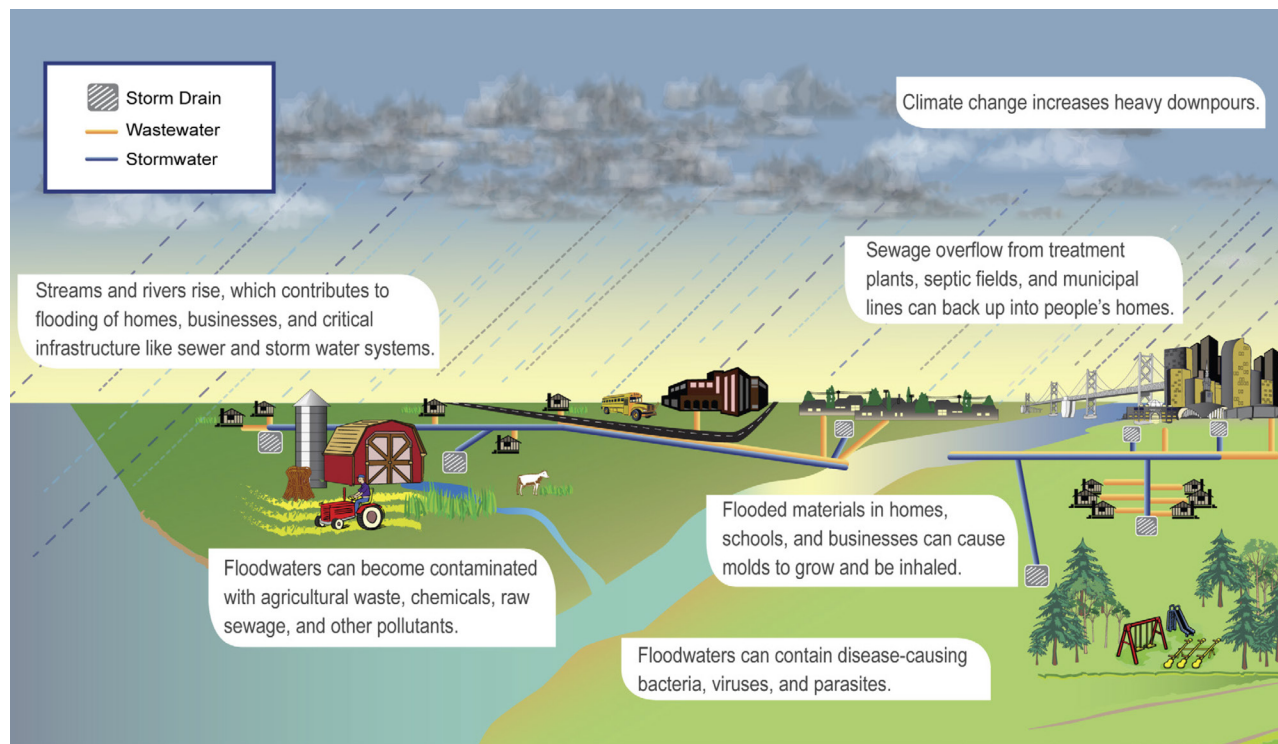


FIGURE 8. Schematic diagram showing how heavy downpours can increase exposure to water contaminants. Figure Melillo et al. (2014).<sup>140</sup>

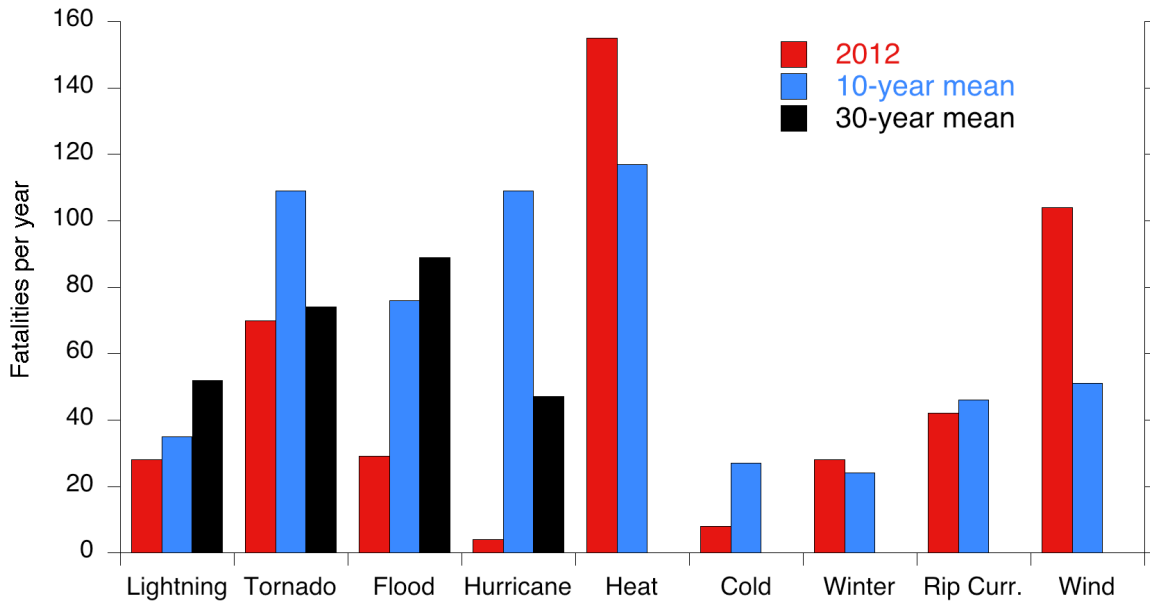
- effects on mental health that may be long lasting in some cases (see Mental Health section below);
- reduced nutritional status, especially among children;
- increased risk of water-related diseases from disruption of water supply or sewerage systems (see Waterborne and Foodborne disease sections below);
- exposure to dangerous chemicals or pathogens released from storage sites and waste disposal sites into floodwaters;
- substantial indirect health impacts can also occur because of damage to the local infrastructure (such as damage to clinics and roads) and population displacement.

Extreme precipitation events are increasing across several areas of the US, including the northeast.<sup>117</sup> Over the past 30 years, floods have been one of the most deadly natural disasters (Figure 9).<sup>118</sup> On average, floods account for approximately 98 deaths per year,<sup>119</sup> most related to drowning.

Projections worldwide show an increase in the number and intensity of extreme storms and flooding events over the next century.<sup>120</sup> Similarly, in the US the frequency and intensity of extreme precipitation events is expected to increase.<sup>121</sup> Storm impacts, particularly hurricanes and heavy precipitation events, are likely to be more severe. The potential for future economic loss in New England, including New Hampshire is high, both as a result of direct damage from coastal storms,<sup>122</sup> and due to the increasing value of vulnerable infrastructure.

**Snowstorms and Ice Storms**

Two forms of extreme winter weather that impact human health are severe snow storms and ice storms. Harmful impacts include power outages; downed power lines and damage to a town’s electrical system make electrocution and fire common risks.<sup>123</sup> Extensive power outages can result in damage to homes (e.g. burst water pipes), considerable mental and stress among the affected populations, and economic distress that negatively impact businesses.<sup>124</sup> The loss of electricity and reliable heat sources also lead to unsafe behaviors, including the improper use of



**FIGURE 9.** Annual weather-related fatalities in the US in 2012, over the last 10 years (2003-2012), and over the last 30 years (1983-2012). Note there is insufficient data to calculate 30-year averages for fatalities related to heat, cold, winter, rip currents or wind. Data from the NOAA – National Weather Service – Office of Climate, Weather, and Water Services.<sup>141</sup>

generators and alternate heat sources such as gas stoves. This in turn has results in carbon monoxide poisoning injuries and deaths.

### **Drought and Wildfires**

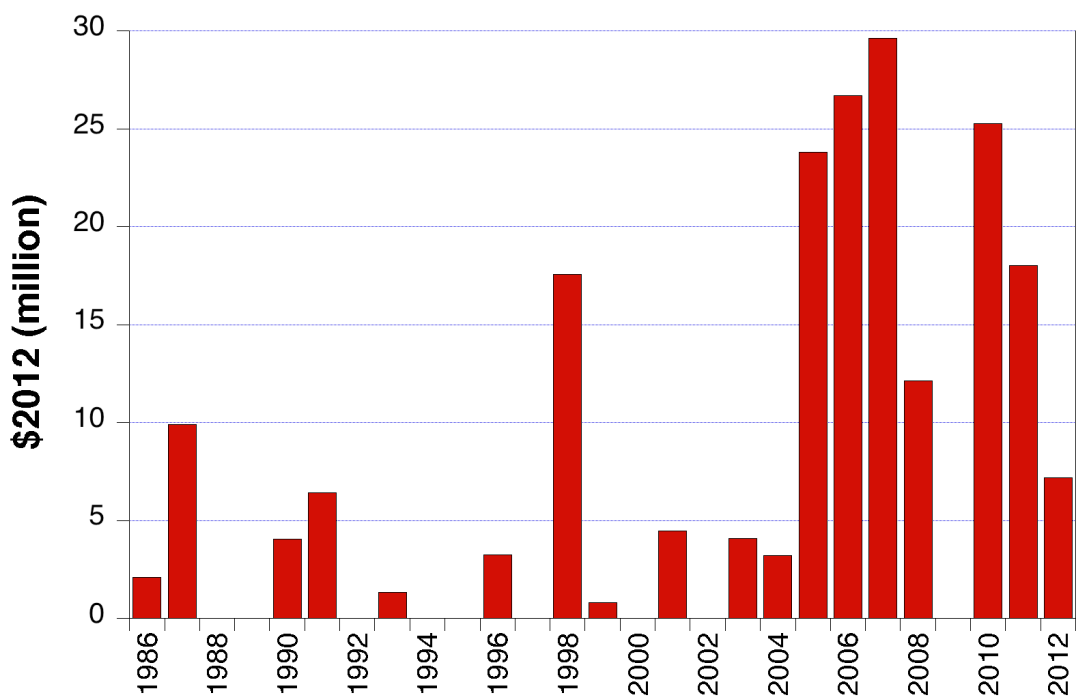
While drought is sometimes defined by lack of precipitation, it is useful to think about drought in terms of soil moisture, which represents the balance of inputs via precipitation and outputs via evaporation. A deficit of soil moisture leads to drought and water shortages. Health related risks associated with prolonged drought include reduction in water supply, food and nutrition, sanitation and hygiene, and recreational risks. NOAA and USDA currently collaborate to provide a weekly map of drought conditions called the US drought monitor.<sup>125</sup>

Wildfire smoke contains a variety of air pollutants, including particulate matter, carbon monoxide, nitrogen oxides, and volatile organic compounds<sup>126</sup> and can lead to degradation of air quality locally and in areas downwind of fires.<sup>127</sup> Smoke exposure has

a wide range of health impacts, including increases in respiratory and cardiovascular hospitalizations, emergency department and medical visits, and has been associated with hundreds of thousands of global deaths annually.<sup>128</sup>

### **4.2.2 Climate Change in New Hampshire: Extreme Weather Events**

New England experiences a range of extreme weather - from extreme precipitation events to nor'easters to ice storms to windstorms to hurricanes to tornadoes - that impact infrastructure, ecosystems, and human health in a variety of ways. One measure of the impact of these extreme weather events is the federal expenditures on Presidentially Declared Disasters and Emergency Declarations (Figure 10; Table 4), although there have been calls for better data to more accurately and consistently measure the socioeconomic impacts of extreme weather events.<sup>129</sup> Note the increase in federal expenditures from extreme weather events in New Hampshire since 2005. A separate measure



**FIGURE 10.** Federal Expenditures on Presidentially Declared Disasters and Emergency Declarations in New Hampshire. Data from FEMA.<sup>142</sup>

Month/Year	Disaster/Emergency Declaration	\$2012 (Millions)
Jan 1998	Ice Storm	24.2
Oct 2005	Alstead/Keene Flooding	15.8
May 2006	Mothers Day Storm & Floods	26.7
April 2007	Patriots Day Storm & Floods	29.6
Aug/Sep 2008	Storms, Tornado & Flooding	11.2
Dec 2008	Sever Winter Storm	15.8
Mar/May 2010	Storms & Flooding	9.7
Aug 2011	Hurricane Irene	12.8
June/Oct 2012	Storm, Flooding & Hurricane Sandy	6.0
March 2013	Sever Winter Storm	5.9

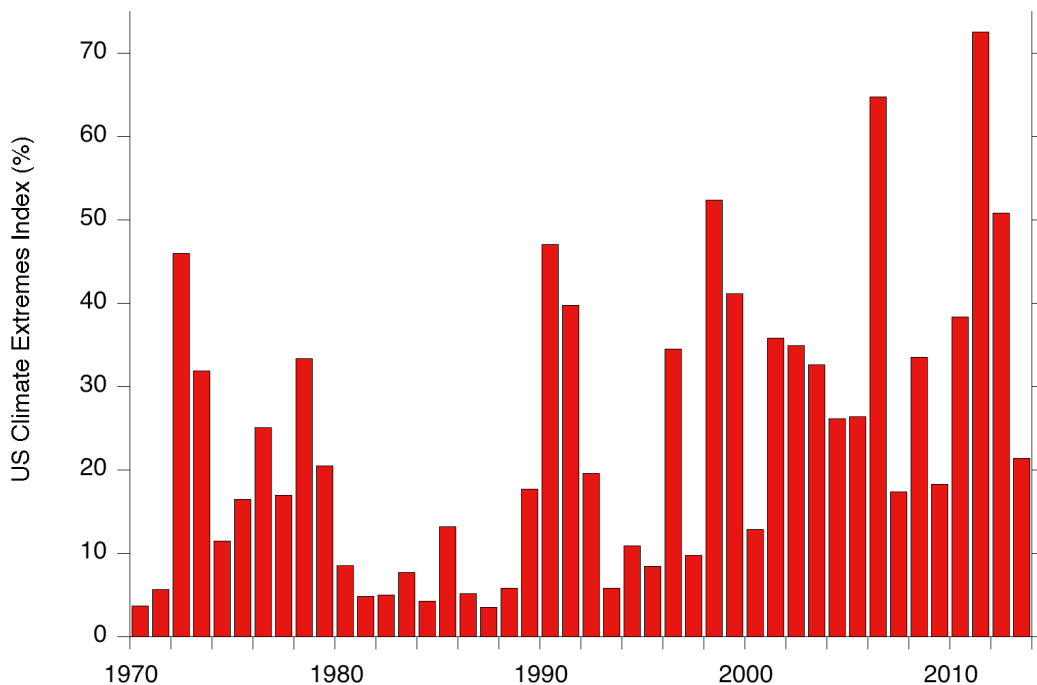
**TABLE 4.** List of the extreme weather events (Presidentially Declared Disasters and Emergency Declarations) in New Hampshire associated with the largest federal expenditures. Data from FEMA.

of trends in extreme weather events for the entire northeast US is provided by the National Oceanographic and Atmospheric Administrations Climate Extremes Index (CEI)<sup>130</sup> (Figure 11) which provides an integrated measure of extremes in temperature, drought, severe moisture surplus, and precipitation. The CEI for the northeast US also shows an increasing trend since the late 1980s.

### Extreme Precipitation (Including Snowstorms)

While overall increases in precipitation have been modest (Chapter 3), 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 across New Hampshire.<sup>131</sup>

Annual precipitation in New Hampshire is expected to increase by 15-20% by the end of the 21<sup>st</sup> century under both emission scenarios (Figure 5 and 6, pg 25). Here we focus on changes in extreme precipitation events, for which there are many definitions:<sup>132</sup> We use three definitions for this report: the number of events per year that drop more than one inch of precipitation in 24 hours and more than two inches of precipitation in 48 hours, and number of events per decade that drop more than four inches of precipitation in 48 hours. There is considerable spatial variability in the projections of future extreme precipitation events (reflecting the current spatial variability in these events) and details for 38 towns and cities across New Hampshire are provided in the climate grids in Appendix A.



**FIGURE 11.** NOAA Climate Extremes Index (CEI) from 1970-2013 for the Northeast US. The CEI provides an integrated measure of extremes in temperature, drought, severe moisture surplus, and precipitation. Data from NOAA.<sup>143</sup>

All the downscaled global climate model simulations show an increase in extreme precipitation events averaged across southern and northern New Hampshire (Tables 2 and 3, pg 26, 27). The number of events per decade that drop four inches in 48 hours is projected to double by the middle of the century, and increase about 2.5 to 3 times by the end of the century, for both southern and northern NH (Figure 12). The smaller events (one inch in 24 hours and two inches in 48 hours) will increase by 20-80% by the middle of the century, and by 30-175% by the end of the century.

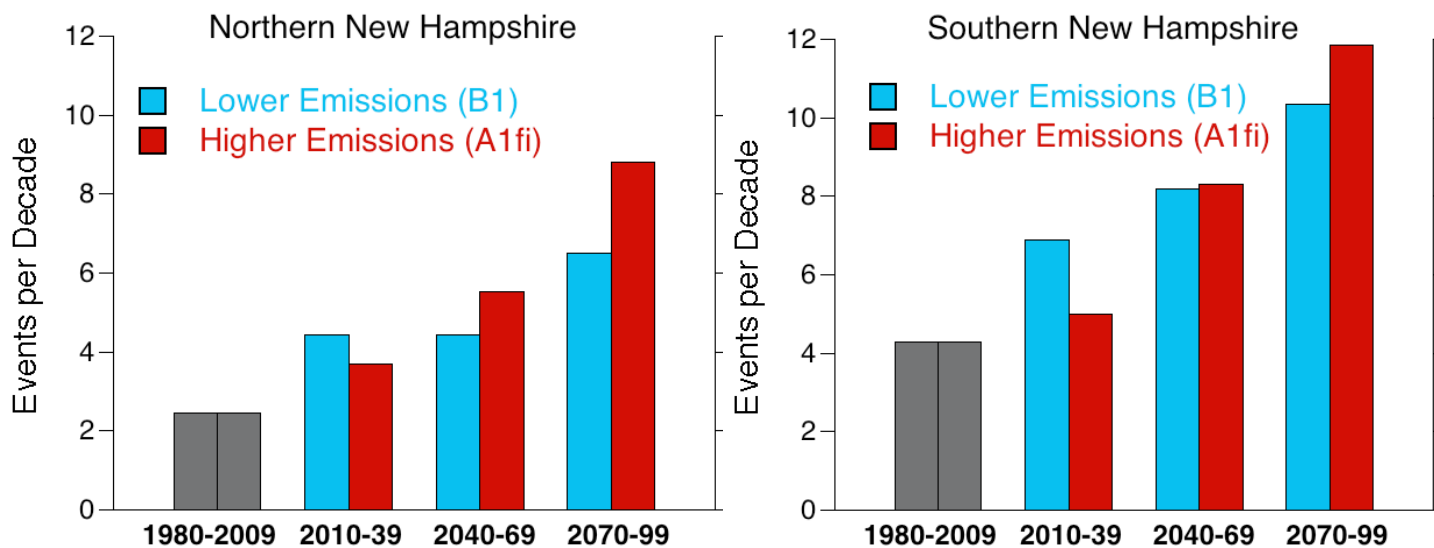
The impacts of changes in extreme precipitation events on flooding across the state are currently being studied in detail for the NH Climate and Health project by USGS scientists. Details will be provided in a separate report. There is also concern regarding an increase in mold exposure and associated negative impacts of respiratory health following flooding events.<sup>133</sup>

### Sea Level Rise and Hurricanes

A significant amount of research has investigated future sea levels and changes in the frequency and magnitude of hurricanes in the North Atlantic. Sea levels are projected to rise between one and two feet by

2050, and by two to six feet by the end of the century.<sup>134</sup> The wide range in sea level rise estimates are the result of uncertainties in the global emission of greenhouse gases, the dynamic response of the Greenland and Antarctic Ice Sheets, and changes in ocean circulation in the North Atlantic. Elevated sea levels will place many New Hampshire communities at risk of flooding from nor'easters and hurricanes. It is expected there will be significant impacts to the various components that comprise the built, natural, and social environments within municipalities. Coastal storms combined with sea level rise increase the risk of erosion, storm-surge damage, and flooding for coastal communities. This means that roadways, bridges, flood and storm water control systems, forests, watersheds, public health systems, buildings, power outages and other aspects of our communities will be affected.

While projected changes in the frequency and intensity of hurricanes resulting from global climate change remain uncertain, recent analyses suggest there may be an increase in both (frequency and intensity) of tropical cyclones in the North Atlantic basin.<sup>135</sup>



**FIGURE 12.** 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 forty-eight hours, shown as thirty-year averages for a) southern New Hampshire (average of forty-one stations), and b) northern New Hampshire (average of twenty-three stations).

## ***Drought and Wildfires***

The drought of the 1960s was the most severe drought experienced by New Hampshire and New England over the past several hundred years.<sup>136</sup> 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.

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.<sup>137</sup> 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 results indicate that over the long-term (2070–2099) under the higher emissions scenario, New Hampshire 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 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. Note that summer precipitation shows only a slight increase, not enough to offset the increase in evapotranspiration resulting from hotter summers.

In July 2002, smoke from forest fires in Quebec has a significant impact on particulate matter air quality across New England and as far south as Baltimore.<sup>138</sup> While there is considerable research of the impact of climate change on forest fires in the western U.S.<sup>139</sup>, there are currently no reliable estimates to our knowledge of the changing frequency or magnitude of forest fires in the northeastern U.S. or eastern Canada due to climate change. However, an increased summer drought projected for the middle – end of the century suggests a return of more frequent forest fires in our region may be cause for concern.

### **4.2.3 Potential Public Health Impact in New Hampshire: Storms and Floods**

A reasonable estimation of future health impacts (including deaths) from extreme weather events in New Hampshire is impeded by the relative absence of empirically documented relationships between extreme weather events and health impacts. Vital statistics data include a cause of death; however, injuries are more difficult to estimate because hospital records do not always document the cause of injury. Despite this limitation, we can estimate that the direct and indirect effects of extreme weather events, especially extreme precipitation events and associated flooding are likely to increase across New Hampshire. Rising seas will also result in an increase in coastal

flooding associated with hurricanes and Nor'easters. We can also expect that some of the longer-term, indirect effects (such as stress and mental-health related impacts) are likely to be a significant issue in terms of both costs and morbidity (see discussion in Section 4.9 on Mental Health).

Although this report does not focus on interventions (Step 3 of the BRACE framework), a consistent theme emerging from this report is the need for multi-sectoral, multi-level (local, regional, state) interventions that connect public health practice to urban planning, storm-water management, integrated watershed resource management, transportation planning, agriculture, and energy systems. Section 4.8 provides some examples of existing multi-sectoral initiatives in NH that could be important partners as the state develops its Climate and Health Adaptation Plan.

### 4.3 Respiratory and Cardiovascular Illness (including asthma)

#### 4.3.1 Summary of Existing Knowledge

Air pollution – in the form of ozone, particulate matter, sulfur dioxide, nitrogen oxides, carbon monoxide – are harmful to human health and the environment. The most widespread health threats are posed by ground level ozone and particulate matter. Ambient levels of regulated air pollutants in the US have generally dropped since the mid-1970s, although air quality in many parts of the country falls short of health-based air quality standards. In 2006, more than 100 million Americans live in areas that exceed the EPA's health-based ozone standard; even potentially low levels of tropospheric ozone are associated with increased risk of premature mortality.<sup>144</sup>

In addition to reducing visibility, fine particles (particulate matter less than 10 microns and less than 2.5 microns; PM<sub>2.5</sub>) can get deep into the lungs and cause serious health problems, including premature death, aggravated asthma, decreased lung

function, coughing, or difficulty breathing. One of the first studies on long-term effects of exposure to low-to-moderate particulate matter (PM) levels was completed by Dockery et al. (1993).<sup>145</sup> They found an association between PM and premature death. Over 8,000 adults in 6 cities in eastern US followed for about 15 years. Laden et al. (2006)<sup>146</sup> extended the study for an additional 8 years (1990-1998). The final results of these studies showed a 16% increase in risk of overall premature death for each 10  $\mu\text{g}/\text{m}^3$  increase in PM<sub>2.5</sub>.

Ozone is a powerful lung irritant, and ozone exposures have been linked to increases in the number of admissions or emergency room visits for respiratory illnesses, diminished lung function, exacerbation of asthma symptoms, and increased risk of premature mortality.<sup>147</sup> Ozone can also exacerbate symptoms of Chronic Obstructive Pulmonary Disease (COPD),<sup>148</sup> which is a consideration for the aging population of New Hampshire.

One of the most comprehensive summaries of the health risks associated with air pollution can be found in a recent "State of the Air" report from the American Lung Association:<sup>149</sup>

- ozone and fine particles are the most widespread air pollutant and threaten the health and lives of millions of Americans;
- within hours of a pollution spike, exposure to air pollution increases hospitalization rates and death from cardiovascular disease;
- short-term increases in fine particle pollution lead to the death of tens of thousands of people every year in the US; and
- longer-term exposure to fine particles (over the course of years instead of days) can shave months to years off of life expectancy. Air pollution increases the risk of death from cardiovascular disease even at levels below current federal and international standards. In matters of the heart, there is no safe level of particle pollution.



Although air pollution is a minor risk factor for cardiovascular disease (CVD) compared to behavioral risk factors such as diet and physical activity, even small risks have a big impact due to the prevalence of CVD. Furthermore, air pollution can affect people's ability to engage in heart-healthy behaviors, such as regular physical activity.

Wilson et al. (2004) conducted a review of time-series studies published since 1993 on the relationship between short-term changes in air quality and use of hospital services, including inpatient and emergency room use.<sup>150</sup> The authors identified three major multicity studies, which analyzed data from over 100 cities in Europe and North America. Air pollutants including ozone (O<sub>3</sub>), particulate matter (PM), nitrogen dioxide (NO<sub>2</sub>) and sulfur dioxide (SO<sub>2</sub>) were significantly associated with increased use of hospital services. The authors conclude that short-term exposure to air pollutants was an important predictor of increased hospital and emergency room use.

Asthma is a chronic condition characterized by inflamed airways and episodes of difficulty breathing. Symptoms include wheezing, coughing, and shortness of breath. The observational evidence indicates that recent regional changes in climate, particularly temperature increases, have already affected a diverse set of physical and biological systems in many parts of the world.<sup>151</sup>

The CDC estimates that over 23 million Americans currently have asthma.<sup>152</sup> Since 1992, the Northeast US has experienced higher rates of asthma related emergency room visits.<sup>153</sup> An assessment of the relationships between air quality (ozone and sulfur dioxide), weather, and respiratory emergency room visits was conducted over the period 1998–2000 in Portland, Maine and 1996–2000 in Manchester, New Hampshire. Relative risks of pollutants were reported; an interquartile range (IQR, the 75<sup>th</sup> –25<sup>th</sup> percentiles) increase in SO<sub>2</sub> was associated with a 5% increase in all respiratory ER visits and a 6% increase in asthma

visits. An IQR increase in O<sub>3</sub> was associated with a 5% increase in Portland asthmatic ER visits. This analysis revealed that, on a daily basis, elevated SO<sub>2</sub> and O<sub>3</sub> have a significant impact on public health in Portland, Maine.

#### **4.3.2 Climate Change in New Hampshire: Respiratory and Cardiovascular Illness**

Analysis of the impact of future climate change on air pollution concludes that warmer temperatures will increase ozone production and summertime ozone concentration in urban areas, while the impact of climate change on the production of fine particulate matter pollution has been inconclusive.<sup>154</sup> Other studies have shown that improving air quality (via either reducing emissions that lead to climate change<sup>155</sup> or reducing automobile traffic<sup>156</sup>) lead to improved health outcomes.

New Hampshire continues to experience ground level ozone exceedances set by the EPA (2008 ozone standard is set at a level of 0.075 part-per-million averaged over an 8-hour period),<sup>157</sup> and also experiences high levels of fine particle pollution in some regions.<sup>158</sup> Over the coming decades, summer climate across the northeast U.S. is projected to be warmer (e.g., Figure 3 and 4, pg 24, 25). Warmer temperatures not only increase the reaction rates that form ozone but also increase emissions of natural ozone precursors (i.e. volatile organic compounds) from plants. The combination of these factors will serve to increase ozone concentrations across the region (under the assumption anthropogenic emissions remain fixed at present day levels).<sup>159</sup> For example, the 8-hour maximum ground-level ozone concentrations in Boston are projected to increase 13 to 21 percent under the higher-emissions scenario and 0 to 5 percent under the lower-emissions scenario.<sup>160</sup>

### 4.3.3 Potential Public Health Impact in New Hampshire: Respiratory and Cardiovascular Illness

The CDC reports that the age-adjusted death rate from coronary heart disease in New Hampshire is 115.9 per 100,000 population.<sup>161</sup> With respect to asthma, the state's prevalence rates are among the highest in the US: 110,000 adults and 25,000 children in New Hampshire suffer from asthma.<sup>162</sup>

In New Hampshire, the projected increase in summertime ozone, as well as lengthening of the "summer" ozone season to include late spring and early fall is likely to lead to more pollution-related illness and death in the state. The uncertainty regarding potential changes in fine-particle pollution due to climate change indicate more research is required before the public health impact can be determined. Obviously, the health effects associated with climate impacts on air pollution will depend - in part - on future air pollution levels.

Previous research in the New York City metropolitan area projected future pediatric asthma emergency department (ED) visits associated with projected changes in ground level ozone.<sup>163</sup> The results suggest an increase in summer ozone-related asthma ED visits of 5-10% across the region by 2020 due to an increase in ozone driven by warming summer temperatures.

## 4.4 Allergies

### 4.4.1 Summary of Existing Knowledge

In the US, allergic disease affects more than 50 million people and represents the sixth leading cause of chronic illness.<sup>164</sup> There is a substantial body of research on the impacts of climate change on aeroallergens and allergic respiratory diseases.<sup>165</sup> Because pollen can adversely influence health outcomes such as allergies and asthma, any increases in pollen associated with climate change could result in an increased burden of asthma and allergies. Warming temperatures and longer growing

seasons are already leading to the exacerbation and development of allergic disease due to changes in the pollen seasons (longer pollen seasons and higher pollen concentrations) and to changes in the allergen content of plants and their pollen.<sup>166</sup> In addition, the increase in carbon dioxide (the raw material required for photosynthesis) is expected to further stimulate plant growth.

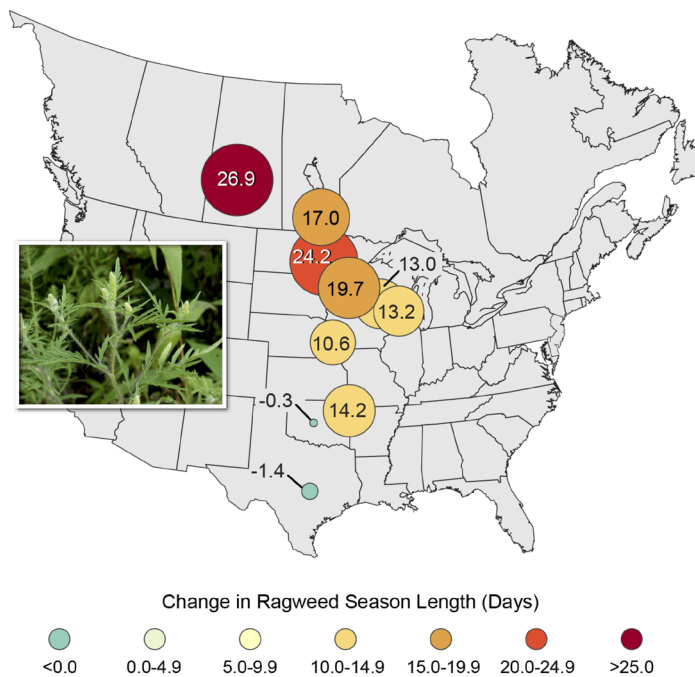
Three distinct seasonal sources of plant pollen are trees (spring), grasses (summer) and weeds (fall). The timing and length of the pollen season depends upon plant responses to weather and climate, and to elevated levels of carbon dioxide. Warming temperatures in Europe over a 35-year period were linked to earlier pollen release.<sup>167</sup> Monitoring in Switzerland and Denmark has shown increased hazel, birch, and grass pollen counts in response to warming.<sup>168</sup> A study of 385 plant species in Britain found that the average date of first flowering had advanced by 4.5 days. European olive trees were found to be pollinating earlier.<sup>169</sup> Climate change has also been linked with longer pollen seasons, greater exposure, and increased disease burden in Montreal for weeds, including mugwort and ragweed.<sup>170</sup> While the underlying mechanisms of all these interactions are not well understood, the consequences on health vary from decreases in lung function to allergic diseases, new onset of diseases, and exacerbation of chronic respiratory diseases.<sup>171</sup>

A series of field and laboratory experiments led by USDA researcher Lewis Ziska have shown that pollen production of ragweed is significantly increased at higher levels of carbon dioxide and warmer temperatures.<sup>172</sup> Research by LeDeau and Clark on the loblolly pine at the Duke University Forest Free-Air CO<sub>2</sub> Enrichment (FACE) facility showed a potential link between elevated carbon dioxide levels and early pollen production (from younger trees) and greater seasonal pollen production.<sup>173</sup> Additional study at the FACE site also showed that poison ivy exposed to high CO<sub>2</sub> levels was also more toxic.<sup>174</sup>

A separate study by Lewis Ziska<sup>175</sup> documented an increase in the length of the ragweed pollen in North America as a function of latitude, associated with warming temperatures that have resulted in a delay in the first frost during the autumn and an increase in the overall length of the frost free period (Figure 13).

#### 4.4.2 Climate Change in New Hampshire: Allergies

Both the lower and higher emission scenarios show warmer average summertime minimum and maximum temperatures in both southern and northern New Hampshire (Figures 3 and 4; Tables 2 and 3) and longer growing seasons (Figure 14). In the short term (2010–2039), the average growing season is likely to be extended by nine to twelve days across New Hampshire, an increase of about six to seven percent. By the end of the century, the growing season is projected to increase by twenty-one days under the lower emission scenarios and by forty-nine to fifty days under the higher emissions scenario across New Hampshire. It is



**FIGURE 13.** Change in the length (days) of ragweed pollen season from 1995 to 2009 as a function of frost-free days, and delays in the time of first frost during the fall, for 10 central North American locations (eight in the United States and two in Canada) as a function of latitude. Figure from Ziska et al.<sup>185</sup>

expected that warmer temperatures, longer growing season, and higher CO<sub>2</sub> levels will likely lead to a significant increase in pollen production across New Hampshire in the future.

However, no assessments of changes in pollen or fungal spores have been completed for New Hampshire or New England<sup>176</sup> and there are no high-quality long-term pollen monitoring stations in New Hampshire that could be used to quantify the relationship between summer warmth, CO<sub>2</sub>, and pollen production. To more accurately assess the intensity and duration of the pollen season in response to anthropogenic warming, standardized local pollen collection should be expanded. Pollen data, relevant meteorological variables, carbon dioxide concentrations, and local land use variables as well as clinical data could address this need, particularly in regard to health-relevant outcomes.<sup>177</sup>

However, across the northeast, lilacs, apples, and grapes also show earlier bloom dates, consistent with the warming trend across the region,<sup>178</sup> and first flowering dates are occurring earlier in Massachusetts.<sup>179</sup> The impact of warmer temperatures across New England has been documented by the changes in USDA plant hardiness zones, defined as the average annual minimum winter temperature, divided into 10°F zones.<sup>180</sup> As winter temperatures have risen over the past several decades, 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.<sup>181</sup>

#### 4.4.3. Potential Public Health Impact in New Hampshire: Allergies

We lack specific information and data to qualitatively or quantitatively assess the impact of climate change in New Hampshire over the past several decades on either: (1) the length or intensity of the pollen season; or (2) allergic reactions, asthma episodes, or lost work or school days. Nonetheless,

warmer temperatures and longer growing seasons, and higher levels of CO<sub>2</sub> are expected to increase pollen production that will increase allergic reactions and asthma episodes in the future. Extreme rainfall and rising temperatures are also expected to increase the growth of fungi and molds, with resulting increases in respiratory and asthma related conditions.

While projections of pollen load are available,<sup>182</sup> there is little to no quality data for New Hampshire that has been used to develop these projections. To address this gap, the development of environmental health indicators for pollen load and presence of ragweed have been recommended.<sup>183</sup> For example, a standardized pollen indicator for a particular region (e.g., annual measures of the start and end dates of pollen season by pollen source, number of days when pollen readings were high or very high, pollen species measured)<sup>184</sup> would be useful for linking pollen levels with health outcome data and for planning.

## 4.5 Vector-borne Disease

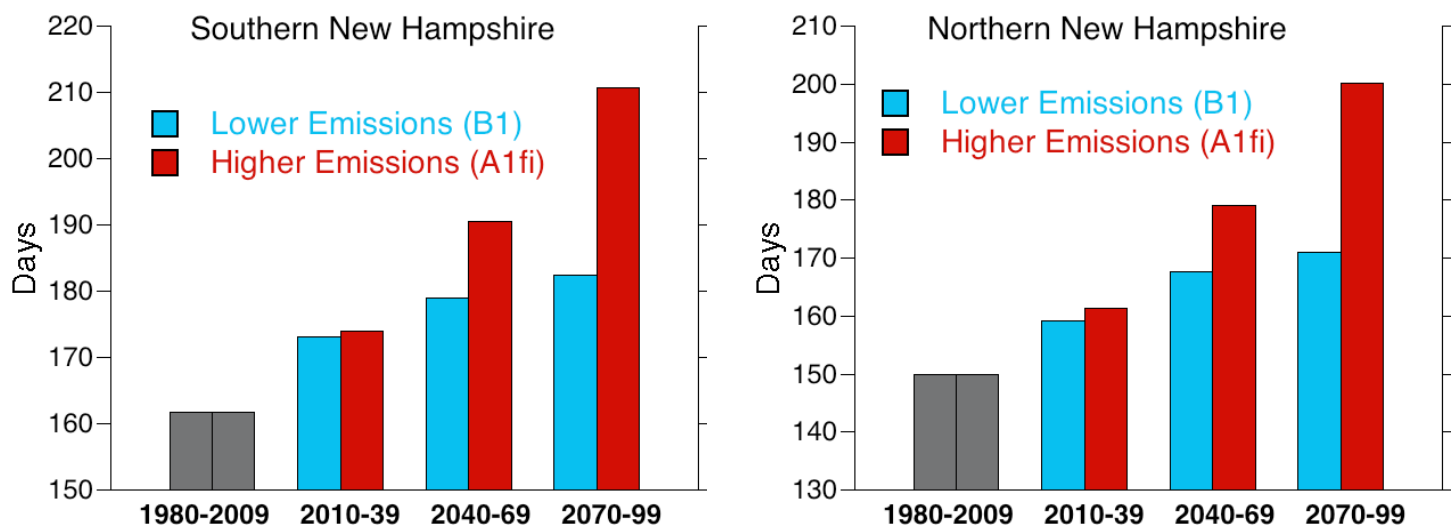
### 4.5.1. Summary of Existing Knowledge

Vector-borne disease results from an infection (bacterial and viral) transmitted to humans and other animals by arthropods, such as mosquitoes, ticks,

and fleas.<sup>186</sup> Examples of vector-borne diseases (VB) include West Nile Virus (MNV), Eastern Equine Encephalitis (EEE) (arboviral), Lyme disease (LD) (bacterial), and malaria.

Changes in temperature, precipitation, and humidity can greatly impact the transmission of vector-borne diseases, specifically relating the incidence and vector range associated with VB.<sup>187</sup> Climate within a continental region appears to influence survival and reproduction rates of vectors, influencing habitat suitability, distribution, and abundance.<sup>188</sup> Thus, climate change may affect the incidence, transmission, and geographic range of various vector-borne diseases.

Based on studies that evaluate the global incidence of vector-borne disease, climate is an important geographic determinant of vectors.<sup>189</sup> However, quantitative research is needed to project the relationship of climate change and vector-borne disease incidence on a specific spatial scale.<sup>190</sup> Similar to worldwide trends, individuals living in North America are currently at risk from climate change-related vector-borne diseases,<sup>191</sup> including LD,<sup>192</sup> WNV,<sup>193</sup> and EEE.<sup>194</sup> This report highlights the major studies for these three important vector-borne diseases.



**FIGURE 14.** 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), and b) northern New Hampshire (average of 15 stations).

## **Lyme Disease<sup>195</sup>**

According to the CDC, Lyme disease is caused by *Borrelia burgdorferi* and is transmitted to humans through the bite of an infected blacklegged tick of the genus *Ixodes*.<sup>196</sup> The development and survival of blacklegged ticks, their animal hosts, and the (LD) bacterium, *B. burgdorferi*, are influenced by many factors, including climate. Depending on the temperature, precipitation, and humidity conditions, regions world-wide are associated with circumstances for infected ticks to flourish.<sup>197</sup> In Europe, LD is caused by infection with the pathogenic species of *Borrelia burgdorferi*, primarily transmitted by *Ixodes ricinus*, also known as sheep tick.<sup>198</sup> In North America, the blacklegged tick *Ixodes scapularis*<sup>199</sup> may be highly dependent on climate patterns.<sup>200</sup> One region with especially suitable climate conditions for LD is the northeastern United States, which consists of a temperate zone ideal for tick survival.<sup>201</sup>

A shift toward warmer temperatures associated with climate change may contribute to the expansion of Lyme *borreliosis* into higher latitudes.<sup>202</sup> However, this scenario may be dependent on whether the vertebrate host species required by relevant tick vectors are able to shift their population distribution.

New information remains to be discovered regarding the factors affecting gene-specific prevalence, transmission, and virulence; however, prevention of tick bites is an efficient public health strategy.<sup>203</sup> Improved distribution of public health information, along with vector control and surveillance programs at appropriate spatial and temporal scales, will further improve effective LD interventions.<sup>204</sup>

## **West Nile Virus**

West Nile virus (WNV) is a mosquito-borne virus that was first introduced in the United States in 1999.<sup>205</sup> WNV includes a self-limiting flu-like condition called West Nile fever that affects 20% of infected patients,<sup>206</sup> as well as more serious neuroinvasive diseases (e.g.,

meningitis, encephalitis) that affect 1 percent of infected patients.<sup>207</sup>

West Nile fever infects birds and humans through the bite of an infected mosquito of the genus *Culex*. Currently, there is not medication or a vaccine to treat or prevent WNV infection.<sup>208</sup> Prior research has shown that summer weather that consists of higher temperatures for longer periods of time combined with dry periods punctuated by heavy rainstorms may be conducive for more frequent outbreaks of mosquito-borne disease such as WNV.<sup>209</sup>

In Europe, there have been a number of WNV outbreaks. However, little is known of the ecology of WNV transmission in relation to climate.<sup>210</sup> Predicting the pattern of when and where outbreaks will occur is challenging, but defining 'windows' of risk conditions through spatial mapping shows some promise.<sup>211</sup>

West Nile virus was not well documented in the US until the summer of 1999, when it first appeared in Queens, NY.<sup>212</sup> In 1999, New York experienced an extremely hot and dry spring and summer, followed by a series of downpours.<sup>213</sup> By 2005, the disease had spread west across the North American continent.

According to some research, the increased climate variability accompanying warming may be more important than the rising heat itself in fueling outbreaks of certain vector-borne illnesses.<sup>214</sup> For example, warm winters followed by hot, dry summers favor the transmission of infections that cycle among birds, urban mosquitoes, and humans, as happened in 1999 when the WNV broke out in North America.<sup>215</sup> Assessing the climatic conditions conducive to outbreaks of WNV and using seasonal climatic forecasts may prove helpful for informing health interventions.<sup>216</sup>

## **Eastern Equine Encephalitis Virus**

Eastern Equine Encephalitis (EEE) virus is associated with the alphavirus genus and the mosquito, *Culiseta melanura* is the vector responsible for the seasonal amplification of EEE.<sup>217</sup> EEE was first

identified in the United States in the 1930's and occurs in the eastern United States, the Gulf Coast, and areas of the Midwest. Symptoms of EEE in humans include fever, vomiting, and headache, as well as seizures, coma, and in rare cases death.

There is no human vaccine and/or treatment for EEE. The first identified human cases occurred in 1938 in southeastern Massachusetts; another epidemic occurred in New Jersey (1959), resulting in 32 cases and 21 deaths. The CDC reported that an EEE epidemic occurred in Massachusetts during 2004 and 2006, followed by an epidemic in New Hampshire.<sup>218</sup>

Armstrong and Andreadis (2013) examined the long-term patterns of EEE and suggested that the increase of human cases is related to wetlands restoration, suburban development, and population growth proximal to EEE habitats.<sup>219</sup> Comprehensive surveillance programs that implement mosquito control measures and public outreach are important strategies to help protect the public from vector-borne diseases.<sup>220</sup> However, without adequate temporal and spatial data, our ability to systematically model associations between climate projections and vector-borne disease incidence is limited.<sup>221</sup>

National and international research has shown that establishing baseline data on the location and count of cases is required to improve early detection of changes that may be related to climate issues.<sup>222</sup> With more applicable spatial and temporal level data, modeling of climate impacts on vector-borne disease could improve our ability to plan adaptation strategies.

#### **4.5.2 Climate Change in New Hampshire: Vector-borne Disease**

As New Hampshire's climate is expected to get warmer and wetter (Table 2 and 3), vector-borne disease incidence may increase.<sup>223</sup> Researchers in NH are actively pursuing the study of vector patterns using complex systems models.<sup>224</sup>

#### **4.5.3 Potential Public Health Impact in New Hampshire: Vector-borne Disease**

Although our understanding of the potential impacts of climate change on vector-borne disease is still in the relatively early stages, expert assessments have concluded that climate change is expected to be among the most important drivers of infectious disease in the future.<sup>225</sup>

In New Hampshire, the projected increase in temperature and precipitation may be associated with expanded habitat for insects of concern, and may lead to a higher incidence of vector-borne disease. It may be informative to consider the fact that a specific type of land cover may be associated with the habitat of EEE vectors and reservoir hosts.<sup>226</sup> For example, analysis of unique hydrographic regions may be used to describe the distribution of lakes, rivers, and streams, and their drainage patterns in relation to precipitation and seasonal climate variables.<sup>227</sup>

In summary, climate change indicators interact with multiple human, biological, and ecological determinants to drive infectious disease in complex ways that require further systems science research.

### **4.6 Foodborne Disease**

In New Hampshire, the projected increase in temperature and precipitation may be associated with warmer seasons that result in more rapid food spoilage, power outages that interrupt refrigeration, and impacts to fisheries and other food economies associated with changes in pathogenic organisms. These harmful conditions may lead to increases in gastrointestinal (GI) illness associated with spoiled food consumption. The health effects of sporadic food poisoning are difficult to track since many people do not always report GI upsets to public health authorities.

#### **4.6.1 Summary of Existing Knowledge**

Nationally, the CDC estimates that approximately 16% of Americans (48 million people) become ill

and 3,000 die of foodborne diseases every year.<sup>228</sup> A foodborne disease outbreak is defined as the incidence of two or more cases of illness caused by a microorganism linked to the same food.<sup>229</sup> The food ingested is typically spoiled or contaminated by 'pathogens' (bacteria, viruses, and microbes) such as *Salmonella* and *Vibrio*. According to a comprehensive synthesis and assessment report of research by the U.S. Climate Change Science Program<sup>230</sup>, climate change may affect the incidence and distribution of foodborne disease. Changing climate conditions have already affected freshwater ecosystems.<sup>231</sup> Indirectly, there is potential for harm from under-nutrition resulting from damage to agricultural crops, economic, and social instability; decreased ability to grow crops and water availability.<sup>232</sup> These factors may contribute to reduce nutritional quality and have a broader impact referred as 'food related' health issues.

Vibriosis caused by the *Vibrio parahaemolyticus* (Vp) and *Vibrio vulnificus* (Vv) strains are recognized as a primary cause of bacterial gastroenteritis in humans associated with seafood consumption in the U.S. and internationally.<sup>233</sup> Both strains live in brackish saltwater.<sup>234</sup> Infection can occur from consumption of raw or undercooked shellfish and seafood.<sup>235</sup> While there are naturally occurring *Vibrio* species in aquatic systems that are not harmful to humans,<sup>236</sup> certain species of *Vibrio* (Vv, Vp) are known to cause disease in humans,<sup>237</sup> which account for a large portion of illnesses each year in the United States.<sup>238</sup>

*Vibrio* gastroenteritis illnesses are increasing globally and may be associated with climate change and the subsequent rise in sea surface temperatures.<sup>239</sup> However, there is yet to be a consensus regarding an association between the increase of *Vibrio* infections and climate warming.<sup>240</sup> According to the CDC, there has been a recent increase in Vp illnesses associated with the consumption of shellfish harvested along the Atlantic coast, United States.<sup>241</sup>

In New Hampshire, disease from *Vibrio spp.* may pose a threat to coastal water quality. Pathogenic vibrio species have been detected in Great Bay, New Hampshire since the 1970's,<sup>242</sup> yet their persistence, distribution, and virulence are not well understood.<sup>243</sup> Research suggests that vibrio bacteria concentrations worldwide,<sup>244</sup> across the U.S.<sup>245</sup> as well as in New England<sup>246</sup> are influenced by a combination of factors (i.e., temperature and salinity), which may vary with season and land-use change.<sup>247</sup> A better understanding of the impact of water quality parameters on the ecology of *Vibrio* abundance is needed to predict the human health impact associated with this organism.<sup>248</sup>

#### **4.6.2 Climate Change in New Hampshire: Foodborne Disease**

As air temperatures rise across New Hampshire in the future (Figures 3 and 4; Tables 2 and 3), the length of the season of warm surface water temperatures are also likely to increase, expanding the thermal habitat for foodborne pathogenic species. Exposure to foodborne pathogens can occur several ways, including through drinking water (associated with fecal contamination), handling or eating seafood (due to natural microbial hazards, toxins, or wastewater disposal), and handling or eating fresh produce (irrigated or processed with contaminated water).<sup>249</sup> As climate variability increases, pathways in which foodborne pathogens spread throughout infrastructure and the ecosystem will likely pose greater threats to human health.

### **4.7 Waterborne Disease**

In New Hampshire, the projected increase in temperature and precipitation will likely be associated with warmer, wetter seasons that can increase the human health impacts associated with waterborne microbial organisms. Waterborne illnesses are tracked by public health officials and improved surveillance

systems can be useful in understanding how pathogens spread in response to climate.

#### 4.7.1 Summary of Existing Knowledge

Waterborne diseases are defined as a human health impact caused by microbial organisms that are spread through water and include water-related illnesses, which can be acquired from a lack of hygiene and sanitation.<sup>250</sup> Transmission to humans can occur through skin contact or ingestion of water contaminated by host pathogens,<sup>251</sup> which can originate from animal fecal waste that contain diarrheal diseases caused by bacteria and protozoa.<sup>252</sup>

According to the literature, modeling projections and impacts of climate change on waterborne disease is somewhat limited. However as the evidence builds, confidence that there is a link between climate change, waterborne disease, and human health may likely grow.<sup>253</sup> According to researchers at the World Health Organization, waterborne diseases worldwide account for greater than a million human deaths annually of which a large percent are attributable to unsafe water supply.<sup>254</sup> Waterborne disease outbreaks may occur during low rainfall conditions when bacteria concentrate, and therefore are not necessarily associated with floods.<sup>255</sup> In Europe, there are acknowledged cases of flooding associated with water-borne disease outbreaks, such as in the United Kingdom,<sup>256</sup> Finland,<sup>257</sup> the Czech Republic,<sup>258</sup> and Sweden.<sup>259</sup> Outbreaks typically involve hospitalized patients afflicted by pathogens including *Campylobacter*, *Giardia*, and *Cryptosporidium*.<sup>260</sup> The actual disease burden in countries such as Europe and the U.S. is difficult to approximate and potentially underestimated. In a study conducted in England and Wales, researchers found that 20% of waterborne outbreaks were associated with a period of low rainfall, compared with 10% associated with heavy rainfall.<sup>261</sup> Further study is needed since droughts and high rainfall may increase

the concentration of effluent pathogens.<sup>262</sup>

There is evidence that Canada has experienced shifts in climate that have impacted native Inuit livelihoods, cultural practices, and health. For example, in the spring of 2000, heavy rainfall in the Canadian town of Walkerton, Ontario resulted in approximately 2,300 illnesses and seven deaths, which were attributed to the drinking water becoming contaminated with *E. coli* O157:H7 and *Campylobacter jejuni*.<sup>263</sup>

Cryptosporidiosis is a diarrheal disease caused by the protozoan parasite *Cryptosporidium*, which is a common waterborne diarrheal illness in the U.S. Milwaukee had one of the largest recorded *Cryptosporidium* outbreaks in U.S. history, affecting 25% of city's population in 1993.<sup>264</sup> The seasonal contamination of surface water in spring is one factor that may explain patterns in these episodic cases.<sup>265</sup>

#### 4.7.2. Climate Change in New Hampshire: Waterborne Disease

In New Hampshire, the projected increase in atmospheric temperature and precipitation events could lead to greater water contamination, and an increase in waterborne disease.<sup>266</sup> For example, inflows of excess nutrient runoff to surface water and increased turbidity from the landscape after a storm event have been linked to higher concentrations of pathogenic bacteria, *Giardia*, *Cryptosporidium*, and other harmful microorganisms.<sup>267</sup> *Giardiasis*, which is caused by *G. intestinalis* is one of the more common waterborne diseases in humans in the United States; it is New Hampshire's most common gastrointestinal disease.<sup>268</sup> In 2007, an outbreak of *giardiasis* in New Hampshire was traced to contamination of well water used for drinking water by the community.<sup>269</sup>

In addition to the direct health hazards associated with waterborne disease and extreme precipitation events other hazards can appear once a storm event has passed. Waterborne disease can present



in the weeks following flood inundation, and water intrusion into buildings which may initiate mold contamination.<sup>270</sup> As research continues, our understanding of how waterborne disease is associated with key climate conditions continues to evolve.

#### **4.7.3 Potential Public Health Impact in New Hampshire: Waterborne Disease**

Outbreaks of waterborne disease, freshwater and marine algal blooms, and increased concentrations of agricultural waste and heavy metals in drinking water sources have been associated with increased atmospheric temperature, greater evaporation and heavy rain events.<sup>271</sup>

During warmer months in New Hampshire, projected drought may increase the demand for water when the supply is reduced. In addition, higher winter-time temperatures could lead to a greater proportion of precipitation that falls as rain rather than snow, and the snowmelt season begins earlier. Snowmelt in areas of New England appears to have shifted forward by 1 to 2 weeks between 1970 and 2000.<sup>272</sup> Extreme precipitation events can impact aquatic ecosystems and municipal water treatment plants,<sup>273</sup> leading to outbreaks from pathogens infiltrating drinking-water reservoirs and persisting in the water distribution system.<sup>274</sup>

In summary, waterborne illness is associated with extreme precipitation events that are likely to increase as climate changes.<sup>275</sup> These complex temporal and spatial conditions have implications for public health messaging around beach closures, recreational activities, food safety, and sanitation.

### **4.8 Health Behaviors and Chronic Disease**

In New Hampshire, the projected increase in temperature and precipitation may be directly associated with warmer, wetter seasons that influence

the ability of people with chronic disease to perform daily functions, engage in healthy behaviors such as physical activity, and respond to emergencies. The effects of climate change on chronic disease are challenging to track as chronic disease usually has multiple causes and triggers. On the other hand, surveillance systems such as the Behavioral Risk Factor Surveillance System (BRFSS) provide a standardized way to collect self-reported behavioral health information in each state.

#### **4.8.1. Summary of Existing Knowledge**

Although the relationship between chronic disease and climate change has received less attention in the literature compared to injuries and acute illnesses, climate change is likely to affect major chronic diseases in complex ways. Long-term conditions such as asthma and allergies have been covered in previous sections, and mental health will be covered in the following section. In this section, the issue of concern is chronic diseases that disproportionately affect the elderly and vulnerable populations, including: cardiovascular disease, chronic respiratory diseases, obesity, and diabetes.

Not only can air pollution and increased heat directly affect those with chronic conditions, but it can alter behaviors and lifestyle choices (e.g., physical activity) that are major modifiable risk factors for multiple chronic diseases.

International research has investigated the potential health benefits of adopting greenhouse gas (GHG) mitigation policies.<sup>276</sup> Scenarios of GHG mitigation were developed for México City, México; Santiago, Chile; São Paulo, Brazil; and New York, New York. The authors estimated that the adoption of readily available technologies to reduce fossil fuel emissions over the next two decades in these cities would reduce particulate matter and ozone, thus avoiding approximately 64,000 premature deaths (95% confidence interval [CI] 18,000-116,000) (including

infant deaths), 65,000 (95% CI 22,000-108,000) chronic bronchitis cases, and 46 million (95% CI 35-58 million) person-days of work loss or other restricted activity.

Climate change and severe weather can restrict the ability of chronic disease populations to remain physically active, access medical care, participate in the workforce, or obtain healthy food. Physical activity and nutrition have direct impacts on obesity, diabetes, cardiovascular disease, some cancers, and certain mental health conditions.<sup>277</sup> One of the most exciting new research directions in climate change/public health collaborations is in the area of “co-benefits” related to many adaptation strategies. For example, many of the same evidence-based policy, environmental, and systems change strategies that have been promoted by the “healthy eating/active living” (HEAL) movement within chronic disease prevention (e.g., promoting access to parks and green space, encouraging multi-modal transportation systems and “smart growth” land use patterns, improving access to affordable healthy food (including local agriculture and farmer’s and farmer’s markets, and promoting “joint use” of school facilities) are also important climate change adaptation strategies. We are just not used to thinking of them as such. Thinking in terms of co-benefits moves beyond single-disease thinking and illustrates how decisions can potentially benefit public health more holistically, along with the environment and economic system.<sup>278</sup> Collaborative processes such as Health Impact Assessment (HIA) and adaptive management can be useful to help multi-sectoral stakeholders envision co-benefits and trade-offs of pending policy and planning decisions.

#### **4.8.2 Potential Public Health Impact in New Hampshire: Health Behaviors and Chronic Disease**

Importantly, climate change may affect key health behaviors (e.g., physical activity, diet), which are among the major modifiable risk factors associated

with cardiovascular disease. For example, rising temperatures may mean that people spend more time outside exercising in fall/winter/spring than they normally would in the Northeast, and less time in the summer. Changes in exercise habits may also change exposure to particulate matter, pollen, and disease vectors, especially for vulnerable populations. Extreme weather events, such as flooding, can make public parks and recreational facilities inaccessible, potentially causing people to abstain from physical activity. Consumption of fruits and vegetables may change as access to locally grown produce changes in response to climate conditions, in terms of both availability and costs. While several relevant studies have been published on sustainable environments, health behaviors and social capital, there have been few in New Hampshire linking climate change to these outcomes.<sup>279</sup>

Both extreme cold and extreme heat have been associated with increased incidence of hospital admissions for chest pain, acute coronary syndrome, stroke, and variations in cardiac dysrhythmias, though the reported magnitude of the exposure-outcome associations is inconsistent<sup>280</sup> Weather conditions such as extreme heat serve as stressors in individuals with pre-existing cardiovascular disease, and can directly precipitate exacerbations.<sup>281</sup>

In summary, vulnerabilities pertaining to behavioral and chronic disease impacts are likely to follow similar socio-demographic patterns as those described previously for other impacts, particularly for the elderly, socially or linguistically isolated individuals, immigrants/refugees, low income individuals, those working in strenuous occupations, and those suffering from disabilities or multiple chronic illnesses. The importance of the way we plan our built environment, including land use, transportation, and water management plans, as well as how we interact with our natural environment and preserve its life-supporting functions, must be emphasized as pivotal

points of intersection in the “Geography of Resilience” framework described at the beginning of this report.

There is an unprecedented window of opportunity in terms of linking the co-benefits of multi-sectoral, multi-level planning initiatives currently being implemented in NH. These include: the work of the NH Regional Planning Commissions on the Granite State Future initiative, hazard-mitigation planning efforts, and local health department initiatives such as neighborhood health improvement strategies. They also include institutional policies on environmental sustainability such as those initiated by NH DES, the work of the UNH Institute on Disability (IOD) on emergency preparedness, Integrated Watershed Resource Management and related partnerships in NH.<sup>282</sup> A common thread running through these diverse initiatives is the potential for multiple public health co-benefits in terms of both mitigation and adaptation.

## 4.9 Mental Health and Stress-Related Disorders

In New Hampshire, the projected increase in temperature and severe weather may affect the ability of people to adapt physically, emotionally, and mentally. High temperatures and flood events are known to lead to more confrontations and violence in urban areas. The effects of climate change on mental health and stress-related disorders is more challenging to track, as these conditions may have multiple causes and triggers. They are often under-reported and are generally not collected in a standardized manner.

### 4.9.1. Summary of Existing Knowledge

An emerging international body of literature is beginning to examine the mental health and stress-related impacts of climate change. Once again, these effects are greatly influenced by the geography of risk described in Chapter 2. Perhaps more than any other domain, the mental health of a population is influenced by the convergence of social-ecological

factors (including constructs pertaining to the social determinants of health – e.g., education, employment, social capital, access to medical and social services) and the natural and built environment. Key climate-related risks that interact with mental health issues include exacerbated water and food insecurity, population displacement due to natural disasters, increased exposure to heat and cold (especially when housing/shelter is inadequate), and reduced access to “buffering systems” (e.g., social support, safe places to walk, green-space).<sup>283</sup> Populations will be differentially vulnerable to these potential impacts at global to local levels. Those at highest risk include populations living in areas with limited technological capacity, weak institutions, high levels of poverty, and social inequality.<sup>284</sup>

For example, an Australian study found that as many as one in five people will suffer from the effects of extreme stress and emotional injury after a severe weather event.<sup>285</sup> These conditions can last for months or even years after a flood as victims continue to struggle with issues such as the loss of their homes or displacement from their communities.<sup>286</sup>

A review of research on indigenous health and climate change has indicated communities can develop adaptive capacity, with active responses to climate-related health risks.<sup>287</sup> However, non-climatic stresses (i.e., poverty, land dispossession, and globalization) pose substantial challenges to this adaptability. The authors recommend that more attention be focused on the global to local interactions that shape local geographies of risk, and that enhanced surveillance along with an evaluation of policy and institutional supports are critical. Emerging evidence also suggests that neighborhood characteristics such as crime and access to open space may mediate or moderate people’s behaviors during extreme weather events.<sup>288</sup>

A review of mental health impacts associated with flooding in the UK<sup>289</sup> found that flooding can pose substantial social and mental health problems. The review assessed the epidemiological evidence

on flooding and mental health, assessed the existing guidance on emergency planning for the impacts of flooding on psychosocial and mental health needs, and provided guidance for policymakers and services on practical methods to reduce the impacts of flooding on the mental health of affected people. The authors emphasize the need to reduce the impact of stressors on people affected by flooding. The authors found that most people's psychosocial needs are met through their social networks - including close relationships with their families, friends and communities; smaller proportions of people are likely to require specialized mental healthcare. They stress the importance of a multi-sector approach that involves communities as well as multi-sectoral government approaches to promote wellbeing and recovery. Family-based approaches, frequently used in behavioral health, are also critically important.

Studies of severe flooding events in the United Kingdom in 2007 suggest that approximately 90 percent of the public health costs of the floods may be attributable to mental health issues.<sup>290</sup> In the US, the advantages of a technological society are potentially a double-edged sword when it comes to mental health and climate-related threats. For example, family and social networks are increasingly dispersed, particularly for elderly persons who often live far from their children and may be socially isolated. Furthermore, the fragmented system of care for persons with mental illness and substance abuse issues is already challenged under current conditions, with little attention paid to the added challenges of climate change. Mental health issues are common after disasters.<sup>291</sup> For example, research has demonstrated a relationship between high levels of anxiety and post-traumatic stress disorder among people affected by Hurricanes such as Katrina.<sup>292</sup>

Six months after Hurricane Andrew struck Florida in 1992, between 20-30% of the area's population met criteria for PTSD, and 33- 45% of adults were depressed.<sup>293</sup> After two years, those numbers remained largely unchanged as the residents struggled to

cope with the aftermath. Hurricane Ike (2008) and Hurricane Katrina (2005) reveal similar stories about the prevalence and persistence of PTSD after a storm. The majority of adults who developed PTSD following Hurricane Katrina had not recovered within 18 to 27 months after the storm.<sup>294</sup>

Other types of mental health issues, such as domestic violence and alcohol abuse, may also rise after extreme weather events. Rates of domestic violence nearly doubled after Hurricane Katrina, and after floods in the Midwest in 1993, rates of both domestic violence and alcohol abuse increased.<sup>295</sup>

A recent report<sup>296</sup> suggests that the incidence of mental and social disorders may rise in the face of climate change. These include depressive and anxiety disorders, post-traumatic stress disorders, substance abuse, suicides, and outbreaks of violence. The elderly, the poor, the very young, and those with existing mental and/or physical health conditions are particularly vulnerable. These demographic groups represent about one half of the American public (approximately 150 million people). An estimated 20% of adults in the U.S. will experience mental health issues in a given year. Almost two-thirds of the over 45 million adults with a mental illness, and almost 90 percent of the over 21 million adults with substance use disorders, go without treatment in the US annually.<sup>297</sup>

In addition, some individuals with mental illness are especially susceptible to particular climate-related effects, such as heat stress.<sup>298</sup> Suicide varies seasonally<sup>299</sup> and rises with hot weather,<sup>300</sup> suggesting potential climate impacts on depression. Dementia is a risk factor for hospitalization and death during extreme heat events.<sup>301,302</sup> Additional potential mental health impacts include the distress associated with environmental degradation<sup>303</sup> and physical displacement.<sup>304</sup>

There is clear evidence that the public health challenges arising in the wake of extreme weather events strains our already taxed health care system. For

example in 1999, Hurricane Floyd had substantial long-term consequences regarding the use of health services. After the storm, significant increases were observed in emergency-room visits, outpatient care, and pharmacy use even one year after the hurricane. These increased demands for health services summed to more than \$13.3 million in Medicaid expenditures in the wake of the storm.

As stated in a NWF (2012) report,<sup>305</sup> the American mental health community, counselors, trauma specialists and first responders may not be prepared to handle the large scale and intensity of climate-related impacts that may arise: *“It is not that we haven’t experienced natural disasters before, but the scientific data show that what lies ahead will be bigger, more frequent, and more extreme than we have ever known.”*

#### **4.9.2 Potential Public Health Impact in New Hampshire: Mental Health and Stress-Related Disorders**

Although New Hampshire is frequently described as one the “healthiest” states with respect to physical health indicators, this assumption belies a harsh reality: New Hampshire ranks close to the bottom in terms of mental health. Specifically, NH ranks second to last in the nation for people in need of substance abuse treatment being able to access adequate care.<sup>306</sup> The public mental health system provides services to only 21% of adults who live with serious mental illnesses in the state. New Hampshire ranks first in the nation for underage alcohol use. Of the 130,000 New Hampshire residents estimated that need treatment for alcohol and other drug disorders, less than 5% per year are able to access treatment.<sup>307</sup> Inadequately funded community supports frequently result in backups at local hospital emergency rooms.

The state has had a 10-Year Plan in place since 2008 which recommends strategies to improve the mental health system. Unfortunately due to state and local budget cuts, progress in implementing these strategies has been limited.

In New Hampshire, there is little study of the mental health impacts associated with climate change indicators. No published studies were found for this report. However, many of the findings reported by Stanke et al. 2012 are likely to be relevant in New Hampshire.<sup>308</sup> The 2010 NH DES report, “Preparing for Climate Change: A Strategic Plan to Address the Health Impacts of Climate Change in New Hampshire,” listed the following with respect to vulnerable populations:

- Improving translation/interpretation services,
- Developing coordinated systems around climate change (no coordination currently), and
- Developing ways to specifically identify/link people vulnerable to climate-related health issues to appropriate services and resources.
- Preparing for greater stress on the emergency care system.
- Preparing for higher incidence of mental health issues, including depressive and anxiety disorders, post-traumatic stress disorders, substance abuse, and suicide. The elderly, the poor, the very young, and those with existing mental and/or physical health conditions are especially vulnerable.
- More information can also be found in the New Hampshire “Death by Degrees” report.<sup>309</sup>

In summary, mental health may be one of the most important climate-related health impacts to focus on the future. Efforts should be made to identify vulnerable populations, understand the barriers to treatment (even under existing climate conditions), and improve access to care for persons affected by extreme weather events. The importance of a multi-sectoral strategy that integrates community- and family-based approaches should be considered. Several projects in NH already embrace a family-centered philosophy for violence prevention and neighborhood health. Connecting efforts to improve individual resilience (grounded in the psychology and social work literatures) with community-based efforts to improve climate resilience, could offer a powerful innovation.

## V. CONCLUSIONS AND FUTURE DIRECTIONS

New Hampshire's climate has become warmer and wetter over the past four decades, and the frequency and intensity of extreme precipitation events have increased considerably. The trend towards warmer and wetter climate in New Hampshire is likely to continue over the course of the 21<sup>st</sup> century (based on detailed analysis of statistically downscaled global climate model simulations). These changes in climate have already had a negative impact on the physical and mental health of New Hampshire residents. These negative impacts will also likely continue into the future.

These climate changes are likely to negatively impact public health outcomes such as heat-related morbidity and mortality, respiratory illness, allergies, vector-borne disease, foodborne disease, waterborne disease, health behaviors/chronic disease, and mental health or stress-related disorders, which can greatly increase medical costs. Thus, we suggest considering climate change as a “key force of change” alongside other forces listed in the NH State Health Improvement Plan.<sup>310</sup>

The state and its residents can address these threats via both reducing emissions of heat-trapping gases<sup>311</sup> and adapting to the climate changes that cannot be avoided. The state has a strong public health system, an adaptable population, and resources to continue to address these issues and prevent risks and harm.

Strategies for adapting to climate change will

require the ability to plan and implement interventions to address climate-related health impacts. The process should include assessments, actual quantitative projecting of specific disease burdens for NH whenever possible, and a multi-sectoral stakeholder engagement to prioritize the critical health impacts, and then identify viable interventions that will work for a particular geographic area or population at-risk. It is likely that this could be achieved with existing resources and staffing in the next few years, if local and state leadership participation was able to be activated, coordinated, and maintained.

As discussed in Sections 4.8 and 4.9, a wide range of actions are available across multiple sectors, including timely public health interventions that have begun to be tested and reported. In addition, improvements to housing, infrastructure, urban design, early warning systems, and coordinated health care and social service systems are required. Although the development of integrated strategies can be challenging, there is also an unprecedented opportunity to recognize the co-benefits that can result from such strategies. For example, protecting natural ecosystems, using low-impact development and green infrastructure, integrating climate change considerations into master plans and hazard mitigation plans, and developing multi-modal transportation systems can simultaneously serve to minimize the health impacts of climate change while also reducing

the risks associated with obesity, diabetes, and cardiovascular disease.<sup>312</sup>

We suggest considering how decisions that people and organizations make on a daily basis can influence a cascade of events that either increase vulnerability or promote resilience to climate change. These decisions cut across multiple sectors and multiple spatial and temporal scales. This “systems approach” frames adaptation and mitigation strategies as components of dynamic and interrelated systems. For example, future adaptation strategies for coastal infrastructure are related to the kinds of mitigation strategies that we put into place today.<sup>313</sup> We also suggest moving from the ‘geography of risk’ perspective to the ‘geography of resilience’ perspective. This entails beginning to identify and address the intersecting spheres of influence —exposures, susceptibilities, and adaptations — that can strengthen our response to climate change.

## Current Conditions in the State of New Hampshire

One way to begin such an approach is to determine appropriate geographies, in partnership with Department of Health and Human Services (DHHS) and local partners. These may include Hospital Service Areas (HSA’s), Public Health Networks (PHN’s), counties, and/or large urban areas.

Social Vulnerability Indices (SVI) have been created through prior research and are now being adapted for the New Hampshire context through ongoing work at NH DHHS.<sup>314</sup> This provides valuable data to inform climate adaptation planning and future public health interventions. The social vulnerability indices rely on data from the Census data and the American Community Survey (ACS) (e.g., income, education, race/ethnicity, disability status, and age); described in the published literature.<sup>315</sup> Other examples of social vulnerability, ecosystem vulnerability, and environmental justice indicators can be found in the

national literature.<sup>316</sup>

It is also imperative to develop an integrated approach to collect data on the early effects of changing weather patterns on climate-sensitive health outcomes and enhance long-term surveillance data on specific health outcomes.

To better assess the relationships between climate and health impacts in New Hampshire in the future, certain data challenges need to be addressed. These include the fragmentation of existing data systems, lack of data at fine-grained spatial and temporal scales, difficulty reconciling HIPPA/privacy policies with the need for spatially/temporally specific data to aid in emergency preparedness and climate adaptation planning efforts, and other issues that require attention. Examples include:

- Improving access to data to develop quantitative models of potential health impacts of climate change that can be used to explore the consequences of a range of socio-demographic and climate scenarios.
- Understanding local- and regional-scale vulnerability and adaptive capacity to characterize the potential risks and the time horizon over which climate risks might arise.
- Using existing (as provided in this report) and emerging downscaled climate projections at the local and regional scale to conduct vulnerability and adaptation assessments that enable adequate response to climate change, and to determine the potential for interactions between climate and other risk factors, including societal, environmental, and economic.
- Improving our understanding of the design, implementation, and monitoring of effective and efficient adaptation options.
- Understanding the co-benefits of mitigation and adaptation strategies.
- Enhancing risk communication and public

health education.

- Developing and applying a framework for multi-sector, multi-level collaboration, using recognized collaborative processes such as Health Impact Assessment (HIA) and adaptive governance.
- Developing data sets integrating social vulnerability indices and environmental health data at policy-relevant spatial scales.
- Using an *equity lens* to engage with communities, especially vulnerable populations, and empower them to become active partners in climate change adaptation strategies.<sup>317</sup>

Modeling of climate change adaptation scenarios can be a useful tool. For example, Lindley and colleagues applied a risk assessment tool and adaptation assessment methods to study the response of the greater Manchester (UK) area to climate change.<sup>318</sup> This explicitly spatial method was developed to address the type of information needed to plan adaptation to climate change. This methodology uses geographic information systems (GIS) to create maps of various risk elements (i.e., elderly population), hazards (i.e., maximum temperatures), and the urban system (i.e., built environment characteristics). A final layer that maps the current vulnerability of the region is then created by overlaying the risk element layers with the hazards layers and the built environment layer. Additional layers that project future exposure can also be created.

The NH DHHS has collaborated with the Community Health Institute to develop a set of disaster scenarios that accurately estimate the impact of climate-related events.<sup>319</sup> Scenarios include the impacts of floods, heat waves, hurricane, winter storms, and an infectious disease pandemic. It should be noted that local communities in NH have already begun modeling climate change adaptation scenarios, particularly related to flooding, through grant-funded projects. As

DHHS improves the EPHT program, opportunities to build on existing efforts should be kept in mind.

However, the most important message is that even without complex models, in many respects, we know the way forward. We know that certain planning and policy decisions that pertain to the sustainability of our land, transportation, food, and water systems (see Section 4.8) offer tremendous, synergistic benefits for public health and the creation of climate-resilient communities. These are frequently termed “no-regrets” options in adaptation planning. Rather than focusing on a particular health issue, no-regrets options are more likely to simultaneously reduce the risk of multiple health impacts.

In summary, there is an unprecedented window of opportunity to connect the co-benefits of multi-sectoral, multi-level planning initiatives currently being implemented in New Hampshire. Such multi-sectoral initiatives have the potential to move beyond a single-disease focus to promote multiple public health benefits, and to positively impact the spectrum of diseases highlighted in the CDC’s BRACE framework.

We suggest considering the ‘spectrum of prevention’ – primary, secondary, tertiary – as a useful lens through which to begin thinking about interventions to address the public health impacts of climate change. This lens can connect public health practice to other sectors (e.g., urban planning, land use and transportation planning, energy, integrated watershed resource management) which are critical partners in this effort. There are valuable lessons to be learned from the interdisciplinary evidence-base on obesity prevention (for example), which emphasizes multi-sectoral partnerships and a systems science approach.<sup>320</sup>

Co-benefits associated with primary/secondary prevention can minimize our vulnerability to almost all the diseases in the CDC’s framework, in contrast to interventions that address one disease at a time. This approach is supported by the Institute of Medicine, the



Prevention Institute, and other notable public health organizations.

Finally, we stress the importance of creating a culture of resilience using social networks. Because public health professionals can not address the impacts of climate change alone, we suggest that efforts should be directed towards intentionally building a network of multi-sectoral partners who can support each other in developing a common understanding of the impacts and vulnerabilities, and ultimately implement coordinated adaptation strategies at local, state, and regional scales. Examples could include integrating climate change adaptation elements into emergency preparedness plans, including health-related climate adaptation strategies into Master Plan revisions and zoning decisions, and partnering closely with the New Hampshire Department of Environmental Services' (DES) climate adaptation initiatives.<sup>321</sup> Valuable lessons can also be learned from other CDC Climate Ready States and Cities.<sup>322</sup>

## ENDNOTES

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- Innovative local health sector initiatives such as Manchester's Roadmaps to Health project (<http://www.rwjf.org/en/grants/grant-records/2012/11/supporting-community-schools-in-manchester-n-h-city-of-manc.html>) and Keene's Vision 2020 initiative ([http://www.cheshire-med.com/images/v2020/vision\\_2020\\_book.pdf](http://www.cheshire-med.com/images/v2020/vision_2020_book.pdf))
- Institutional policies on environmental sustainability such as those initiated by NH DES
- The work of the UNH Institute on Disability (IOD) on emergency preparedness (<http://iod.unh.edu/Projects/dph/EmergencyPreparedness.aspx>)
- Integrated Watershed Resource Management, and related partnerships in NH ([http://southeastwatershedalliance.org/wp-content/uploads/2013/02/GI\\_IntroFlyer\\_v81.pdf](http://southeastwatershedalliance.org/wp-content/uploads/2013/02/GI_IntroFlyer_v81.pdf); <http://exeternh.gov/planning/cape-climate-adaptation-plan-exeter>)
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