Synthesis and Assessment Product 4.6

Chapter 3

Effects of Global Change on Human Health

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3.1 Introduction

Weather, climate variability, and climate change can affect health directly and indirectly. Directly, extreme weather (floods, droughts, windstorms, fires and heatwaves) affect the health of Americans and cause significant economic impacts. Indirectly, climate change can alter or disrupt natural systems, making it possible for vector, water-, and foodborne diseases to spread or emerge in areas where they had been limited or not existed, or for such diseases to disappear by making areas less hospitable to the vector or pathogen (NRC, 2001). Climate also can affect the incidence of diseases associated with air pollutants and aeroallergens. The cause-and-effect chain from climate change to changing patterns of health outcomes is often complex and includes factors such as initial health status, financial resources, effectiveness of public health programs, and access to medical care. Therefore, the severity of future impacts will be determined by changes in climate as well as by concurrent changes in nonclimatic factors and by adaptations implemented to reduce negative impacts.

A comprehensive assessment of the potential impacts of climate variability and change on human health in the United States was published in 2000 as part of the First National Assessment of the Potential Impacts of Climate Variability and Change undertaken by the U.S. Global Change Research Program. This Health Sector Assessment examined potential impacts and identified research and data gaps to be addressed in future research; results appeared in a special issue of *Environmental Health Perspectives* (May 2001). The Health Sector Assessment's conclusions on the potential health impacts of climate change in the United States included:

- Populations in Northeastern and Midwestern U.S. cities are likely to experience the greatest number of illnesses and deaths in response to changes in summer temperatures (McGeehin and Mirabelli, 2001).
- The health impacts of extreme weather events hinge on the vulnerabilities and recovery capabilities of the natural environment and the local population (Greenough *et al.*, 2001).
- If the climate becomes warmer and more variable, air quality is likely to be affected. However, uncertainties in climate models make the direction and degree of change speculative (Bernard and Ebi, 2001).
- Federal and State laws and regulatory programs protect much of the U.S. population from waterborne disease. However, if climate variability increases, current and future deficiencies in areas such as watershed protection, infrastructure, and storm drainage systems will probably increase the risk of contamination events (Rose *et al.*, 2000).
- It is unlikely that vector- and rodent-borne diseases will cause major epidemics in the U.S. if the public health infrastructure is maintained and improved (Gubler *et al.*, 2001).
- Multiple uncertainties preclude any definitive statement on the direction of potential future change for each of the health outcomes assessed (Patz *et al.*, 2000).

The assessment further concluded that much of the U.S. population is protected against adverse health outcomes associated with weather and/or climate by existing public health and medical care systems, although certain populations are at increased risk.

This chapter of Synthesis Assessment Product 4.6 updates the Health Sector Assessment. It also examines adaptive strategies that have been or are expected to be developed by the public health community in response to the challenges and opportunities posed by climate variability and change. Part 1 focuses on climate-related impacts on human morbidity and mortality from extreme weather, vector-, water- and foodborne illnesses, including zoonotic diseases, and changes in air quality. For each health endpoint, the assessment addresses the potential impacts, populations that are particularly vulnerable, and research and data gaps that, if bridged, would allow significant advances in future assessments of the health impacts of global change. The assessment includes research published from 2001 through early 2007 in the U.S. or in Canada, Europe, and Australia, where results may provide insights for U.S. populations.

This chapter first summarizes the current burden of climate-sensitive health determinants and outcomes for the U.S., before assessing the potential health impacts of global change. Two types of studies are assessed: those that increase our understanding of the associations between weather variables and health outcomes, and those that project the burden of health outcomes using climate scenarios. The first type of study raises potential concerns, assuming exposure-response relationships do not change.

It is important to note that the assessment focuses on how global change could affect the future health of Americans. However, the net impact of any changes will depend on many other factors, including demographics; population and regional vulnerabilities; the future social, economic, and cultural context; availability of resources and technological options; built and natural environments; public health infrastructure; and the availability and quality of health and social services.

Part 2 focuses on adaptation to the potential health impacts of environmental change in the United States. It also considers public health interventions (including prevention, response, and treatment strategies) that could be revised, supplemented, or implemented to protect human health in response to the challenges and opportunities posed by global change; and how much adaptation could achieve.

3.2 Climate-Sensitive Health Outcomes in the U.S.

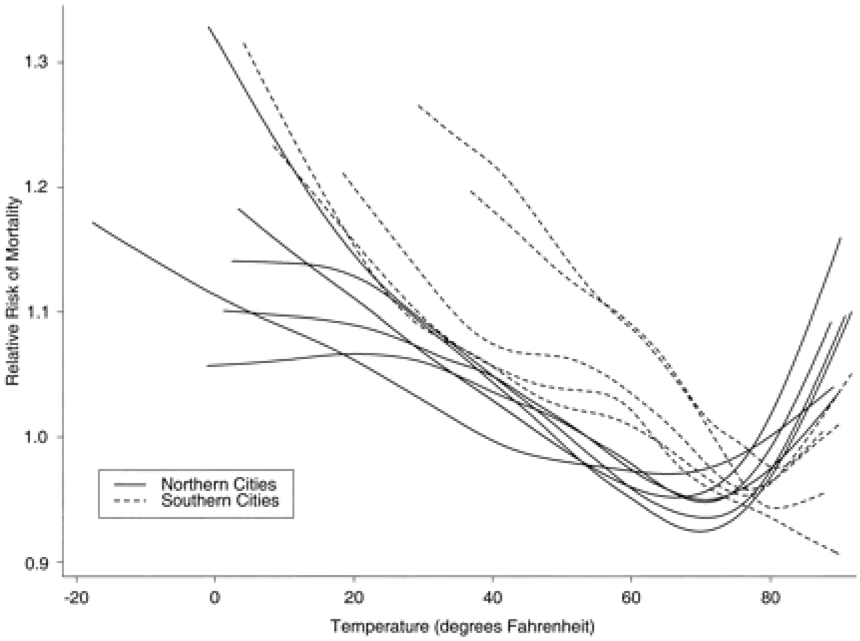
Extreme Weather

Excess deaths occur during heatwaves; on days with higher-than-average temperatures; and in places where summer temperatures vary more or where extreme heat is rare (see Figure 1; relative risks calculated using multiple regression analysis) (Braga et al. 2001). Exposure to excessive natural heat caused a reported 4,780 deaths during the period 1979 to 2002, and an additional 1,203 deaths had hyperthermia reported as a contributing factor (CDC 2005). These numbers are under estimates of the total mortality associated with heatwaves. Heat is expected to contribute to the exacerbation of chronic health conditions, and several analyses have seen associations with cause-specific mortality-cardiovascular, renal, respiratory, diabetes, nervous system disorders and other causes, not specifically described as heat-related (Conti et al. 2007; Fouillet et al. 2006; Medina-Ramon et al. 2006). Among the most well-documented heatwaves in the U.S. are those that occurred in 1980 (St. Louis and Kansas City, Missouri), 1995 (Chicago, Illinois), and 1999 (Cincinnati, Ohio; Philadelphia,, Pennsylvania; and Chicago). In all these episodes, the highest death rates occurred in people over 65 years of age.

Less information exists on temperature-related morbidity, and those studies that have examined hospital admissions and temperature have not seen consistent effects, either by cause or by demonstrated coherence with mortality effects where both deaths and hospitalizations were examined simultaneously (Kovats et al. 2004; Michelozzi et al. 2006; Schwartz et al. 2004; Semenza et al. 1999). EPA is funding additional research on morbidity outcomes since the data are readily available from administrative datasets (EPA 2006a).

Age, fitness, body composition, and level of activity are important determinants of how the human body responds to exposure to thermal extremes (DeGroot et al. 2006; Havenith et al. 1995; Havenith et al. 1998; Havenith 2001). Groups particularly vulnerable to heat-related mortality include the elderly, very young, city-dwellers, those with less education, people on medications such as diuretics, the socially isolated, the mentally ill, those lacking access to air conditioning, and outdoor laborers (Diaz et al. 2002; Klinenberg 2002; McGeehin and Mirabelli 2001; Semenza et al. 1996; Whitman et al. 1997) (Basu et al. 2005; Gouveia et al. 2003; Greenberg et al. 1983; O'Neill et al. 2003; Schwartz 2005) (Jones et al. 1982; Kovats et al. 2004; Schwartz et al. 2004; Semenza et al. 1999; Watkins et al. 2001). A sociological analysis of the 1995 Chicago heatwave found that people living in neighborhoods without public gathering places and active street life were at higher risk, highlighting the important role that community and societal characteristics can play in determining vulnerability (Klinenberg 2002).

Figure 1. Temperature-mortality relative risk functions for 11 U.S. cities, 1973–1994. Northern cities: Boston, Massachusetts; Chicago, Illinois; New York, New York; Philadelphia, Pennsylvania; Baltimore, Maryland; and Washington, DC. Southern cities: Charlotte, North Carolina; Atlanta, Georgia; Jacksonville, Florida; Tampa, Florida; and Miami, Florida. °C = 5/9 x (°F – 32). (Curriero et al. 2002) Permission to use: journals.permissions@oxfordjournals.org.



Urban heat islands may increase heat-related mortality by raising air temperatures in cities 2-10^{o} F over the surrounding suburban and rural areas, due to absorption of heat by dark paved surfaces and buildings, lack of vegetation and trees, heat emitted from buildings, vehicles, and air conditioners, and reduced air flow around buildings (EPA 2005; Pinho and Orgaz 2000; Vose et al. 2004; Xu and Chen 2004). However, in some regions, urban areas may not experience greater heat-related mortality than in rural areas (Sheridan and Dolney 2003).

The health impacts of high temperatures and high air pollution can interact, with the extent of interaction varying by location (Bates 2005; Goodman et al. 2004) (Goodman et al. 2004; Keatinge and Donaldson 2001; O'Neill et al. 2005; Ren et al. 2006).

Cold

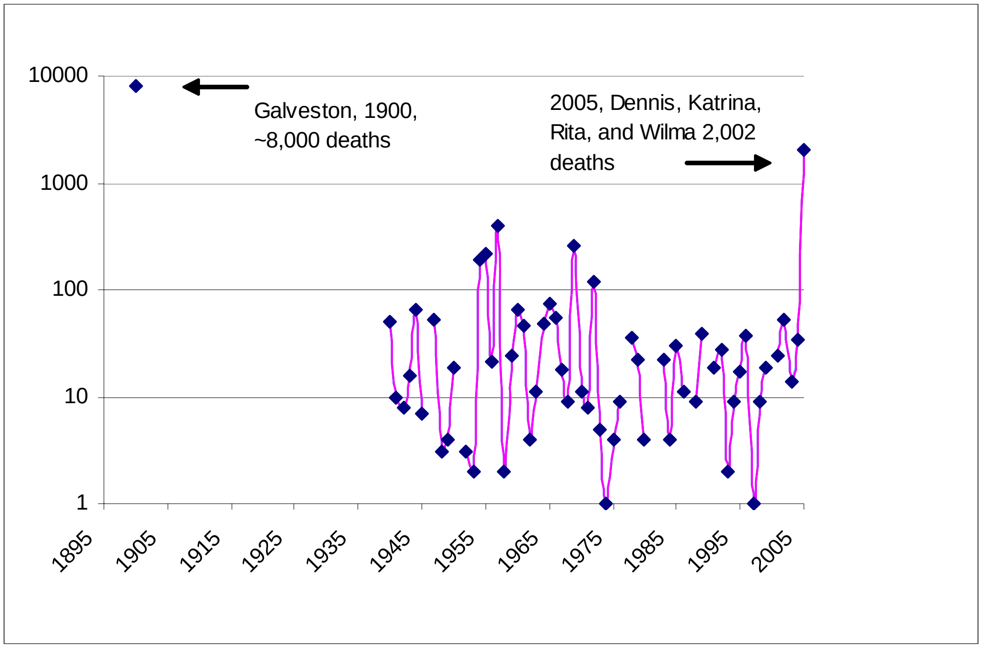
From 1979 to 2002, an average of 689 reported deaths per year (range 417-1,021), totaling 16,555 over the period, were attributed to exposure to excessive natural cold (Fallico et al. 2005). Cold also contributes to deaths caused by respiratory and cardiovascular diseases, so the overall mortality burden is likely underestimated. Factors associated with increased vulnerability to cold include black race (Fallico et al. 2005); living in Alaska, New Mexico, North Dakota, and Montana or living in a milder states that experience rapid temperature changes (North and South Carolina) and western states with greater ranges in nighttime temperatures (e.g., Arizona) (Fallico et al. 2005); having less education (O'Neill et al. 2003); and being female, having pre-existing respiratory illness (Wilkinson et al. 2004), lack of protective clothing (Donaldson et al. 2001), income inequality, fuel poverty, low residential thermal standards (Healy 2003), and living in nursing homes (Hajat et al. 2007).

Hurricanes, Floods, and Wildfires

The United States experiences a wide range of extreme weather events, including hurricanes, floods, tornadoes, blizzards, windstorms, and drought. Other extreme events, such as wildfires, are strongly influenced by meteorological conditions. Direct morbidity and mortality due to an event increase with the intensity and duration of the event, and can decrease with advance warning and preparation. Health also can be affected indirectly. Examples include carbon monoxide poisonings from portable electric generator use following hurricanes (CDC, 2006c) and an increase in gastroenteritis cases among hurricane evacuees (CDC, 2005a). The mental health impacts (e.g. post traumatic stress disorder, depression) of these events are likely to be especially important, but are difficult to assess (Middleton *et al.*, 2002; Russoniello *et al.*, 2002; Verger *et al.*, 2003; North *et al.*, 2004; Fried *et al.*, 2005; Weisler *et al.*, 2006). However, failure to fully account for direct and indirect health impacts may result in inadequate preparation for and response to future extreme weather events.

Figure 2 shows the annual number of deaths attributable to hurricanes in the U.S. from the 1900 Galveston storm, (NOAA, 2006), records for the years 1940-2004 (NOAA, 2005a), and a summary of a subset of the 2005 hurricanes (NOAA, 2007). The data shown are dominated by the 1900 Galveston storm and a subset of 2005 hurricanes, particularly Katrina and Rita, which together accounted for 1,833 of the 2,002 lives lost in 2005 (NOAA, 2007). The 2005 hurricane season doubled the estimate of the average number of lives lost to hurricanes in the U.S. over the previous 65 years.

Figure 2. Annual Deaths Attributed to Hurricanes in the United States, 1900 and 1940-2005



Source: NOAA, 2007

A wildfire's health risk is largely a function of the population in the affected area and the speed and intensity with which the wildfire moves through those areas. Wildfires can increase eye and respiratory illnesses due to fire-related air pollution. Climate conditions affect wildfire incidence and severity in the West (Westerling *et al.*, 2003; Gedalof *et al.*, 2005; Sibold and Veblen, 2006). Between 1987-2003 and 1970-1986, there was a nearly fourfold increase in the incidence of large Western wildfires (i.e., fires that burned at least 400 hectares) (Westerling *et al.*, 2006). The key driver of this increase was an average increase in springtime temperature of 0.87°C that affected spring snowmelt, subsequent potential for evapotranspiration, loss of soil moisture, and drying of fuels (Running, 2006; Westerling *et al.*, 2006).

Indirect Health Impacts of Climate Change

The observation that most vector-, water- or foodborne and/or animal-associated diseases exhibit a distinct seasonal pattern suggests *a priori* that weather and/or climate influence their distribution and incidence. The following sections arbitrarily differentiate between zoonotic and water- and foodborne diseases, although many water- and foodborne disease are zoonotic.

Vectorborne and Zoonotic (VBZ) Diseases

Transmission of infectious agents by blood-feeding arthropods (particular insect or tick species) and/or by non-human vertebrates (certain rodents, canids, and other mammals) has changed significantly in the U.S. during the past century. Diseases such as rabies and cholera have become less widespread and diseases such as typhus, malaria, yellow fever, and dengue fever have largely disappeared, primarily because of environmental modification and/or socioeconomic development (Philip and Bozeboom, 1973; Beneson, 1995; Reiter, 1996). At the same time, other diseases expanded their distribution either because of suitable environmental conditions (including climate) or enhanced detection (examples include Lyme disease, ehrlichioses, and Hantavirus pulmonary syndrome) or were introduced and are expanding their range due to appropriate climatic and ecosystem conditions (West Nile Virus). Still others are associated with non-human vertebrates that have complex associations with climate variability and human disease (e.g. plague, influenza). The burden of VBZ diseases in the U.S. is not negligible and may grow in the future because the forces underlying VBZ disease risk simultaneously involve weather/climate, ecosystem change, social and behavioral factors, and larger political-economic forces that are part of globalization. In addition, introduction of pathogens from other regions of the world is a very real threat.

Few original research articles on climate and VBZ diseases have been published in the U.S. and in other developed temperate countries since the First National Assessment,. Overall, these studies provide evidence that climate affects vector and tick abundance and distributions of vectors and ticks that can carry West Nile virus, Western Equine encephalitis, Eastern Equine encephalitis, Bluetongue virus, and Lyme disease, and perhaps disease risk, but in sometimes in counter-intuitive ways that do not necessarily translate to increased disease incidence (Wegbreit and Reisen, 2000; Subak, 2003; McCabe and Bunnell, 2004; DeGaetano, 2005; Purse *et al.*, 2005; Kunkel *et al.*, 2006;

Ostfeld *et al.*, 2006; Shone *et al.*, 2006). Changes in other factors such as hosts, habitats, and human behavior are also important.

Waterborne and Foodborne Diseases

Water and foodborne diseases continue to cause significant morbidity in the U.S. In 2002, there were 1,330 food-related disease outbreaks (Lynch *et al.*, 2006), 34 outbreaks from recreational water (2004), and 30 outbreaks from drinking water (2004) (Dziuban *et al.*, 2006; Liang *et al.*, 2006). For outbreaks of foodborne disease with known etiology, bacteria (Salmonella) accounted for 55% and viruses accounted for 33% (Lynch *et al.*, 2006). Viral associated outbreaks rose from 16% in 1998 to 42% in 2002, primarily due to increases in norovirus (Lynch *et al.*, 2006). In recreational water, bacteria accounted for 32% of outbreaks, parasites (primarily *Cryptosporidium*) for 24%, and viruses 10% (Dziuban *et al.*, 2006). Likewise in drinking water outbreaks of known etiology, bacteria were the most commonly identified agent (29%; primarily *Campylobacter*), followed by parasites and viruses, which were each identified 5% of the time (2003 – 2004; Liang *et al.*, 2006). Gastroenteritis continues to be the primary disease associated with food and water exposure. In 2003 and 2004, gastroenteritis was noted in 48% and 68% of reported recreational and drinking water outbreaks, respectively (Dziuban *et al.*, 2006; Liang *et al.*, 2006).

Water- and foodborne disease remain highly underreported (e.g., Mead *et al.*, 1999). Few people seek medical attention and of those that do, few cases are diagnosed (many pathogens are difficult to detect and identify in stool samples) or reported. Using a combination of underreporting estimates, passive and active surveillance data, and hospital discharge data, Mead *et al.* (1999) estimated that over 210 million cases of gastroenteritis annually in the U.S., including over 900,000 hospitalizations and over 6,000 deaths. These numbers far exceed previous estimates. Of the total estimated annual cases, just over 39 million can be attributed to a specific pathogen and approximately 14 million are transmitted by food. Of the cases with known etiology patterns differ somewhat from that reported for outbreaks, with the highest frequency of illness caused by viruses (67%; primarily noroviruses), followed by bacteria (30%; primarily *Campylobacter* and *Salmonella*) and parasites (3%; primarily *Giardia* and *Cryptosporidium*). While the outcome of many gastrointestinal diseases is mild and self limiting, they can be fatal or significantly decrease fitness in vulnerable populations including young children, the immunocompromised, and the elderly. Children ages 1-4 and older adults (>80 years) each make up more than 25% of hospitalizations involving gastroenteritis, but older adults contributed to 85% of the associated deaths (Gangarosa *et al.*, 1992). Clearly, as the U.S. population ages, the economic and public health burden of diarrheal disease will increase proportionally without appropriate interventions.

Most pathogens of concern for food- and waterborne exposure are enteric and transmitted by the fecal-oral route. Climate may influence the pathogen directly by influencing its growth, survival, persistence, transmission or virulence. Likewise, there may be important interactions between land-use practices and climate variability. For example, incidence of foodborne disease associated with fresh produce is growing (FDA 2001). Storm events and flooding may result in the contamination of food crops (especially produce such as leafy greens and tomatoes) with feces from nearby livestock or feral animals. Therefore, changing climate or environments may alter or facilitate transmission of pathogens or affect the ecology and/or habitat of zoonotic reservoirs.

Studies in North America (U.S. and Canada) (Fleury *et al.*, 2006; Naumova *et al.*, 2006), Australia (D'Souza *et al.*, 2004), and several countries across Europe (Kovats *et al.*, 2004a) report striking similarities in correlations between peak ambient temperatures (controlled for season) and peak in clinical cases of salmonellosis. Over this broad geographic range, yearly peaks in salmonellosis cases occur within 1 to 6 weeks of the highest reported ambient temperatures. Mechanisms suggested include replication in food products at various stages of processing (D'Souza *et al.*, 2004; Naumova *et al.*, 2006) and changes in eating habits during warm summer months (i.e., outdoor eating) (Fleury *et al.*, 2006). Additionally, because *Salmonella* are well adapted to both host conditions and the environment they can grow readily even under low nutrient conditions at warm temperatures (e.g., in water and associated with fruits and vegetables) (Zhuang *et al.*, 1995; Mouslim *et al.*, 2002). Evidence supports the notion that increasing global temperatures will likely increase rates of salmonellosis; however, additional research is needed to determine the critical drivers behind this trend (i.e., intrinsic properties of the pathogen or extrinsic factors related to human behavior).

The possible effects of increasing temperatures on *Campylobacter* infection rates and patterns cannot be reliably projected. The apparent seasonality of campylobacteriosis incidence is more variable than salmonellosis and temperature models are less consistent in their ability to account for the observed infection patterns. In the northeastern U.S., Canada, and the U.K., *Camplyobacter* infection peaks coincide with high annual daily or weekly temperatures (Louis *et al.*, 2005; Fleury *et al.*, 2006; Naumova *et al.*, 2006). However, in several other European countries, campylobacteriosis rates peak earlier, before high annual temperatures, and in those cases temperature accounts for only 4% of the interannual variability (Kovats *et al.*, 2005b). *Campylobacter* spp. cannot replicate in the environment and will not persist long under non-microaerophilic conditions, suggesting that high ambient temperatures would not contribute to increased replication in water or in food products.

Leptospirosis is a re-emerging disease in the U.S. and is the most widespread zoonotic disease in the world (Meites *et al.*, 2004). While it has not been a reportable disease nationally since 1995, several states continue to collect passive surveillance data and cases continue to be reported (Katz *et al.*, 2002; Meites *et al.*, 2004). Because increased disease rates are linked to warm temperatures, epidemiological evidence suggest that climate change may increase the number of cases.

Vibrio spp. (primarily *V. vulnificus*) account for 20% of sporadic shellfish-related illnesses and over 95% of deaths (Lipp and Rose 1997; Morris 2003). While the overall incidence of illness from *Vibrio* infections remains low, the rate of infection increased 41% since 1996 (Vugia *et al.*, 2006). *Vibrio* spp. are more frequently associated with warm climates (e.g. Janda *et al.*, 1988; Lipp *et al.*, 2002). Coincident with proliferation in the environment, human cases also occur during warm temperatures. In the US, the highest case rates occur in the summer months (Dziuban *et al.*, 2006). Given the close association between temperature, the pathogen, and disease, it has been suggested that increasing temperatures may increase the geographic range and disease burdens of *Vibrio* pathogens (e.g., Lipp *et al.*, 2002). For example, increasing prevalence and diversity of *Vibrio* spp. has been noted in northern Atlantic waters of the U.S. coincident with warm water (Thompson *et al.*, 2004). Additionally, although most cases of *V. vulnificus* are attributed to Gulf Coast states, this species have been isolated from temperate and northern waters in the U.S. (Pfeffer *et al.*, 2003; Randa *et al.*, 2004).

The most striking example of increased range in pathogen distribution and incidence was documented in 2004, when an outbreak of shellfish-associated *V. parahaemolyticus* was reported from Prince William Sound in Alaska (McLaughlin *et al.*, 2005). *V. parahaemolyticus* had never been isolated from Alaskan shellfish before and it was thought that Alaskan waters were too cold to support the species (McLaughlin *et al.*, 2005). In the period preceding the July 2004 outbreak, water temperatures in the harvesting area consistently exceeded 15^{o} C and the mean daily water temperatures were significantly higher than in the prior six years (McLaughlin *et al.*, 2005). This outbreak extended the northern range of oysters known to contain *V. parahaemolyticus* and cause illness by 1,000 km. Evidence is highly suggestive that increasing global temperatures will lead to an increased burden of disease associated with certain *Vibrio* spp., especially *V. vulnificus* and *V. parahaemolyticus*.

Protozoan parasites, particularly *Cryptosporidium* and *Giardia*, contribute significantly to waterborne and to a lesser extent foodborne disease burdens in the U.S. Both parasites are zoonotic and form environmentally resistant infective stages, with only 10-12 oocysts or cysts required to cause disease. In 1998, 1.2 cases per 100,000 of cryptosporidiosis were reported in the U.S. (Dietz and Roberts, 2000); the immunocompromised are at particularly high risk (Casman *et al.*, 2001; King and Monis, 2006). Between 2003 and 2004, of the 30 reported outbreaks of gastroenteritis from recreational water 78.6% were due to *Cryptosporidium* and 14.3% were due to *Giardia* (Dzuiban *et al.*, 2006). *Giardia* has historically been the most commonly diagnosed parasite in the U.S.; between 1992 and 1997 there were 9.5 cases per 100,000 people (Furness *et al.*, 2000). Both *Cryptosporidium* and *Giardia* case reports peak in late summer and early fall, particularly among younger age groups (Dietz and Roberts, 2000; Furness *et al.*, 2000). For both parasites, peak rates of reported infection in Massachusetts occurred approximately one month after the annual temperature peak (Naumova *et al.*, 2006). The lagged association between peak annual temperatures and peaks in reported cases in late summer has been attributed to increased exposure during the summer bathing season, especially in the younger age groups, and a slight lag in reporting (Dietz and Roberts 2000; Furness *et al.*, 2000; Casman *et al.*, 2001). With increasing global temperatures, an increase in recreational use of water can be reasonably expected and may lead to increased exposure among certain groups, especially children.

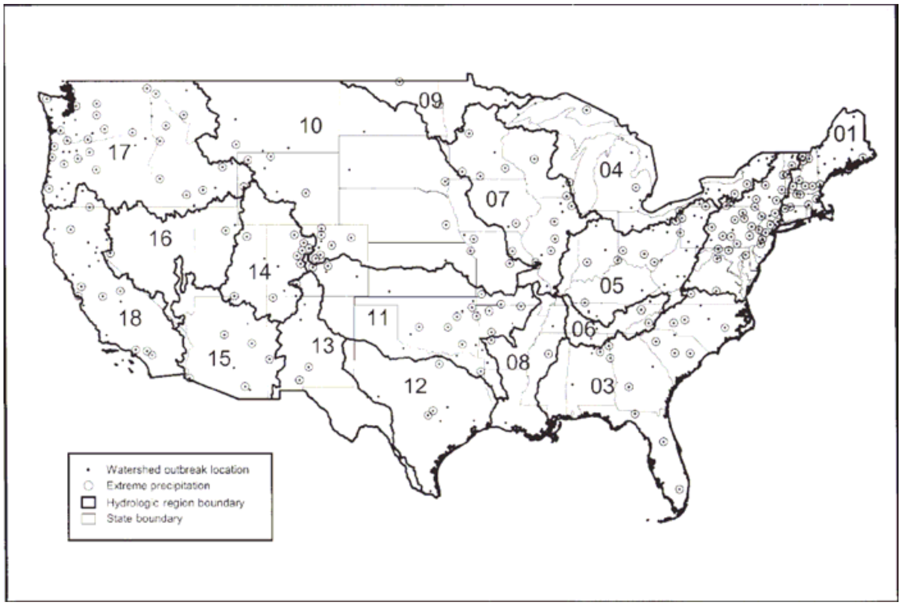
Naegleria fowleri is a free-living amboeboflagellate found in lakes and ponds at warm temperatures, either naturally or in thermally polluted bodies of water. While relatively rare, infections are almost always fatal (Lee *et al.*, 2002). *N. fowleri* can be detected in environmental waters at rates up to 50% (Wellings *et al.*, 1977) at water temperatures above 25^{o} C (Cabanes *et al.*, 2001). Cases are consistently reported in the U.S.; between

1999 and 2000, four cases (all fatal) were reported. While *N. fowleri* continues to be a rare disease, it remains more common in the U.S. than elsewhere in the world (Marciano-Cabral *et al.*, 2003). Given its association with warm water, elevated temperatures might be expected to increase this pathogen's range.

Epidemiologically significant viruses for food and water exposure include enteroviruses, rotaviruses, hepatitis A virus, and norovirus. Viruses account for 67% of foodborne disease, and the vast majority of these are due to norovirus (Mead *et al.*, 1999). Rotavirus accounts for a much smaller fraction of viral foodborne disease (Mead *et al.*, 1999), but is a significant cause of diarrheal disease among infants and young children (Charles *et al.*, 2006). Enteroviruses are not reportable and therefore incidence rates are poorly reflected in surveillance summaries (Khetsuriani *et al.*, 2006). With the exception of hepatis A (Naumova *et al.*, 2006), enteric viral infection patterns follow consistent year to year trends. Enteroviruses are characterized by peaks in cases in the early to late summer (Khetsuriani *et al.*, 2006), while rotavirus and norovirus infections typically peak in the winter (Cook *et al.*, 1990; Lynch *et al.*, 2006). No studies have been able to identify a clear role for temperature in viral infection patterns.

An analysis of waterborne outbreaks associated with drinking water in the United States between 1948 and 1994 found that 51% of outbreaks occurred following a daily precipitation event in the 90th percentile and 68% occurred when precipitation levels reached the 80th percentile (Curriero *et al.*, 2001) (Figure 3). Similarly, Thomas *et al.* (2006) found that risk of waterborne disease doubled when rainfall amounts surpassed the 93rd percentile. Rose *et al.* (2000) found that the relationship between rainfall and disease was stronger for surface water outbreaks but the association was significant for both surface and groundwater sources. In 2000, groundwater used for drinking water in Walkerton, Ontario was contaminated with *E. coli* O157:H7 and *Campylobacter* during rains that surpassed the 60-year event mark for the region and the 100-year event mark in local areas (Auld *et al.*, 2004). In combination with preceding record high temperatures, 2,300 people in a community of 4,800 residents became ill (Hrudey *et al.*, 2003; Auld *et al.*, 2004).

Figure 3. Drinking Waterborne Disease Outbreaks and 90%-ile Precipitation Events (a two month lag precedes outbreaks); 1948 – 1994.



Source: Curriero *et al.*, 2001

Flood waters may increase the likelihood of contaminated drinking water and lead to incidental exposure to standing flood waters. In 1999, Hurricane Floyd hit North Carolina and resulted in severe flooding of much of the eastern portion of the state, including extensive hog farming operations. Residents in the affected areas experienced over twice the rate of gastrointestinal illness following the flood (Setzer and Domino, 2004). Following the severe floods of 2001 in the Midwest, contact with floodwater was shown to increase the rate and risk of gastrointestinal illness, especially among children (Wade *et al.*, 2004); however, consumption of tap water was not a risk factor as drinking water continued to meet all regulatory standards (Wade *et al.*, 2004).

Influenza

Influenza may be considered a zoonosis in that pigs, ducks, etc. serve as non-human hosts to the influenza viruses (e.g. H3N2, H1N1) that normally infect humans (not H5N1). A number of recent studies evaluated the influence of weather and climate variability on the timing and intensity of the annual influenza season in the U.S. and Europe. Results indicated that cold winters alone do not predict pneumonia and influenza (P&I)-related winter deaths, even though cold spells may serve as a short-term trigger (Dushoff *et al.*, 2005); and that regional differences in P&I mortality burden may be attributed to climate patterns and to the dominant circulating virus subtype (Greene *et al.*, 2006). Studies in France and the U.S. demonstrated that the magnitude of seasonal transmission (whether measured as mortality or morbidity) during winter seasons is significantly higher during years with cold El Niño Southern Oscillation (ENSO) conditions than during warm ENSO years (Flahault *et al.*, 2004; Viboud *et al.*, 2004), whereas a study in California concluded that higher temperatures and El Nino years increased hospital admissions for viral pneumonia (Ebi *et al.*, 2001). In an attempt to better understand the spatio-temporal patterns of ENSO and influenza, Choi *et al.* (2006) used stochastic models (mathematical models that take into account the presence of randomness) to analyze California county-specific influenza mortality, and produced maps that showed different risks during the warm and cool phases. In general, these studies of influenza further support the importance of climate drivers at a global and regional scale, but have not advanced our understanding of underlying mechanisms.

Valley Fever

Valley fever (Coccidioidomycosis) is an infectious disease caused by inhalation of the spores of a soil-inhabiting fungus that thrives during wet periods following droughts. The disease is of public health importance in the desert southwest. In the early 1990s, California experienced an epidemic of Valley Fever following five years of drought (Kolivras and Comrie, 2003). Its incidence varies seasonally and annually, which may be partly due to climatic variations (Kolivras and Comrie, 2003; Zender and Talamantes, 2006). If so, then climate change may affect its incidence and geographic range.

Morbidity and Mortality Due to Changes in Air Quality

Millions of Americans continue to live in areas that do not meet the health-based National Ambient Air Quality Standards (NAAQS) for ozone and fine particulate matter (PM2.5). Both ozone and PM2.5 have well-documented health effects, and levels of these two pollutants have the potential to be influenced by climate change in a variety of ways.

Ground-level ozone is formed mainly by reactions that occur in polluted air in the presence of sunlight. Nitrogen oxides (emitted mainly by burning of fuels) and volatile organic compounds (emitted both by burning of fuels and by evaporation from vegetation and stored fuels) are the key precursor pollutants for ozone formation. Ozone formation increases with greater sunlight and higher temperatures, it reaches peak concentrations during the warm half of the year, and then mostly in the late afternoon and early evening. It has been firmly established that breathing ozone results in short-term, reversible decreases in lung function as well as burning of the cells lining the lungs. In addition, epidemiology studies of people living in polluted areas have suggested that ozone may increase the risk of asthma-related hospital visits (Schwartz, 1995), premature mortality (Kinney and Ozkaynak, 1991; Bell *et al.*, 2004), and possibly the development of asthma (McConnell *et al.*, 2002). Vulnerability to ozone health effects is greater for persons who spend time, especially with physical exertion, outdoors during episode periods because this results in a higher cumulative dose to the lung. Thus, children, outdoor laborers, and athletes may be at greater risk than people who spend more time indoors and who are less active. At a given lung dose, little has been firmly established about vulnerability as a function of age, race, and/or existing health status. However, because their lungs are inflamed, asthmatics are potentially more vulnerable than non-asthmatics.

PM2.5 is a far more complex pollutant than ozone, consisting of all airborne solid or liquid particles that share the property of being less than 2.5 micrometers in aerodynamic diameter.1 All such particles are included, regardless of their size, composition, and biological reactivity. PM2.5 has complex origins, including primary particles directly emitted from sources and secondary particles that form via atmospheric reactions of precursor gases. Most of the particles captured as PM2.5 arise from burning of fuels, including primary particles such as diesel soot and secondary particles such as sulfates and nitrates. Epidemiologic studies have demonstrated associations between both short-term and long-term average ambient concentrations and a variety of adverse health outcomes including respiratory symptoms such as coughing and difficulty breathing, decreased lung function, aggravated asthma, development of chronic bronchitis, heart attack and arrhythmias (Dockery et al., 1993; Samet *et al.*, 2000; Pope *et al.*, 1995, 2002, 2004; Pope and Dockery 2006; Dominici et al, 2006; Laden et al., 2006). Associations have also been reported for increased school absences, hospital admissions, emergency room visits, and premature mortality. Susceptible individuals include people with existing heart and lung disease, and diabetes, children and older adults. Because the mortality risks of PM2.5 appear to be mediated through narrowing of arteries and resultant heart impacts, persons or populations with high blood pressure and/or pre-existing heart conditions are likely to be at increased risk. In a study of mortality in relation to long-term PM2.5 concentrations in 50 U.S. cities, persons without a high school education demonstrated higher concentration/response functions that those with more education (Pope *et al.*, 2002), which may reflect differential exposures or differential responses given exposure, or some combination of both.

3.3 Projected Health Impacts of Global Change in the US

Heat-Related Mortality

Determinants of how climate change could alter heat-related mortality include actual changes in the mean and variance of future temperature; factors affecting temperature variability at the local scale; demographic characteristics of the population; and policies that affect the social and economic structure of communities, including urban design, energy policy, water use, and transportation planning. Residential and industrial development will increase over the coming decades, which will likely increase urban heat islands in the absence of urban design and new technologies to reduce heat loads.

The U.S. population is aging; the percent of the population over age 65 is projected to be 13% by 2010 and 20% by 2030 (over 50 million people) (Day 1996). Older adults are physiologically and socially vulnerable (Khosla and Guntupalli 1999; Klinenberg 2002) to hot weather and heatwaves, suggesting that heat-related mortality could increase. Evidence that diabetics are at greater risk of heat-related mortality (Schwartz 2005), along with the increasing prevalence of obesity and diabetes (Seidell 2000; Visscher and Seidell 2001), suggests that reduced fitness and higher-fat body composition may contribute to increased mortality.

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[1] Aerodynamic diameter is defined in a complex way to adjust for variations in shape and density of various particles, and is based on the physical diameter of a water droplet that would settle to the ground at the same rate as the particle in question. For a spherical water particle, the aerodynamic and physical diameters are identical.

Table 1 summarizes projections of temperature-related mortality either in the U.S. or in temperate countries whose experience is relevant to the U.S. (Dessai 2003) (Woodruff et al. 2005) (Knowlton et al. in press) (CLIMB 2004; Hayhoe et al. 2004). Similar studies are underway in Europe (Kosatsky et al. 2006; Lachowsky and Kovats 2006). All studies used downscaled projections of future temperature distributions in the geographic region of interest. The studies used different approaches to incorporate likely future adaptation.

Table 1: Projections of Impacts of Climate Change on Heat-Related Mortality

Location	Period	Adaptation considered	Projected Impact on Heat-Related Deaths
Lisbon, Portugal[1]	2020s, 2050s compared to 1980-1998	yes	Increase of 57%-113% in 2020's, 97-255% in 2050s, depending on adaption
8 Australian cities[2]	2100 compared to 1990s	no	Increase of 1700 to 3200 deaths, depending on policy approach followed and age structure of population
New York, NY[3]	2050s compared to 1990s	yes	Increase 47% to 95%; reduced by 25% with adaptation
California[4]	2090s compared to 1990s	yes	Depending on emissions, mortality increases 2-7 fold from 1990 levels, reduced 20-25% with adaption
Boston, MA[5]	projections to 2100 compared to 1970-92	yes	Decrease after 2010 due to adaptation

1 Dessai, 2003
2 Woodruff, 2005
3 Knowlton, in press
4 Hayhoe, 2004
5 CLIMB, 2004

The impacts projected for Lisbon were more sensitive to the choice of regional climate model than the method used to calculate excess deaths, and the author described the challenge of extrapolating health effects at the high end of the temperature distribution, for which data are sparse or nonexistent (Dessai 2003).

Time-series studies also can shed light on potential future mortality during temperature extremes. Heat-related mortality has declined over the past decades (Davis et al. 2002; Davis et al. 2003a; Davis et al. 2003b). A similar trend, for cold and heat-related mortality, was observed in London over the last century (Carson et al. 2006). The authors speculate that these declines are due to increasing prevalence of air-conditioning (in the U.S.), improved health care, and other factors. To use these results to suggest that increases in heat-related mortality may not occur in the U.S. (Davis et al. 2004), it is necessary to assume that mortality during temperature extremes will continue to decline at the same rate, even though the percentage of the population with access to air conditioning is high in most regions and improvements in health care have stalled in recent years. Further, population level declines may obscure persistent mortality impacts in vulnerable groups.

Hurricanes, Floods, and Wildfires

No studies have projected the future health burdens of extreme weather events. However, there is a theoretical basis for concern that climate change will increase the frequency and/or severity of extreme events, including hurricanes, floods, and wildfires.

Theoretically, climate change could increase the frequency and severity of hurricanes by warming tropical seas where hurricanes first emerge and gain most of their energy (Pielke *et al.*, 2005; Trenberth, 2005; Halverson, 2006). Controversy over whether hurricane intensity increased over recent decades stem less from the conceptual arguments than from limitations of hurricane incidence data (Halverson, 2006; Landsea, 2005; Pielke *et al.*, 2005; Trenberth, 2005). Even if climate change increases the frequency and severity of hurricanes, it will be difficult to definitively identify this trend for some time because of the relatively short and highly variable historical data available as a baseline for comparison.

Although, on average, the number of extreme precipitation events has increased over time, (Balling Jr. and Cerveny, 2003; Groisman *et al.*, 2004; Kunkel, 2003), seasonal and regional patterns are not as consistent (Groisman *et al.*, 2004). Overall, general circulation models (GCMs) project increases in mean precipitation with a disproportionate increase in the frequency of extreme precipitation events (Senior *et al.*, 2002). The IPCC concluded that it is very likely (>90% certainty) that trends in extreme precipitation will continue in the 21st century (IPCC, 2007). Kim (2003) used a regional climate model to project that a doubling in CO2 concentrations in roughly 70 years could increase by roughly 33% the number of days with at least 0.5 mm of precipitation across the study’s defined elevation gradients in the western U.S.

GCMs project that key meteorological variables for wildfires, as well as vegetative cover, will be affected by climate change. Climate change may also affect human activity, notably patterns of residential development and resource use, resulting in direct and indirect pressures on wildfires. Therefore, there is reason to believe climate change could affect the incidence and severity of wildfires in the U.S.

Factors independent of the impacts of and responses to climate change will affect vulnerability to extreme events, including population growth, continued urban sprawl, population shifts to coastal areas, and differences in the degree of community preparation for extreme events. All else equal, these increases mean more U.S. residents will be at risk for future extreme weather events and that more health impacts can be anticipated.

Vectorborne and Zoonotic Diseases

Modeling the possible impacts of climate change on VBZ diseases is complex, and few studies have made projections for diseases of concern in the U.S. Studies suggest that temperature influences the distributions of Ixodes spp. ticks that transmit pathogens causing Lyme disease in the U.S. (Brownstein *et al.*, 2003) and Canada (Ogden *et al.*, 2006), and tick-borne encephalitis in Sweden (Lindgren *et al.*, 2000). Higher minimum temperatures were generally favorable to the potential of expanding tick distributions and greater local abundance of these vectors. However, changing patterns of tick-borne encephalitis (TBE) in Europe are not consistently related to changing climate (Randolph, 2004a). Climate change is projected, based on a multivariate statistical analysis of current areas of risk, to decrease the geographic range of TBE in areas of lower latitude and elevation as transmission expands northward (Randolph and Rogers, 2000).

Water- and Foodborne Diseases

Several important pathogens that are commonly transmitted by food or water may be susceptible to changes in replication, survival, persistence, habitat range, and transmission under changing climatic and environmental conditions (Table 2). Many of these agents show seasonal infection patterns (indicating potential underlying environmental or weather control), are capable of survival or growth in the environment, or are capable of waterborne transport. Factors that may affect these pathogens include changes in temperature, precipitation, extreme weather events (i.e., storms), and ecological shifts.

Table 2. Possible Influence of Climate Change on Climate Susceptible Pathogens and/or Disease

Pathogen	Exposure Routes	Possible Influence of Climate Change	Confidence in Changes[a]	References
Bacteria				
Salmonella	**Food**	**Increasing temperature associated with increasing clinical cases**	**High**	**D'Souza *et al.*, 2004; Kovats *et al.*, 2004a; Fleury *et al.*, 2006; Naumova *et al.*, 2006**
		Precipitation and run-off associated with increased likelihood of contamination of produce	**Medium[b]**	**Haley 2006; Holley *et al.*, 2006**
	Water	**Increasing temperature associated with increasing clinical cases**	**High**	**D'Souza *et al.*, 2004; Fleury *et al.*, 2006; Kovats *et al.*, 2004a; Naumova *et al.*, 2006**
		Shifts in habitat and range of reservoirs may influence potential contact	**Medium[b]**	
Campylobacter	**Food**	**Increasing temperatures may contribute to**	**Medium**	**Newel, 2002**

		seasonal carriage rates among reservoirs and thereby increase rates		
	Water	**Increased precipitation may increase likelihood of contamination of drinking water sources due to run off**	**Medium**	**Auld *et al.*, 2004; Vereen *et al.*, 007**
		Increasing temperatures may contribute to seasonal carriage rates among reservoirs and thereby increase rates	**Medium**	**Newel, 2002**
		Shifts in habitat and range of reservoirs may influence potential contact	**Medium[b]**	
***Vibrio* spp.**	**Food**	**Increased ambient temperatures associated with growth in post-harvest shellfish and increased disease**	**Very High[c]**	**Cook, 1994**
	Water	**Increasing temperature associated with higher environmental prevalence and disease**	**High**	**Janda *et al.*, 1988; Lipp *et al.*, 2002; McLaughlin et al. 2005; Dziuban *et al.*, 2006**
		Increasing temperature associated with range expansion	**High**	**McLaughlin *et al.*, 2005**
		Increased precipitation and fresh water run off leads to depressed estuarine salinities and increase in some *Vibrio* spp.	**Medium**	**Lipp *et al.*, 2001b; Louis *et al.*, 2003**

		Sea level rise and or storm surge increase range and human exposure	Medium	Lobitz *et al.*, 2000
Leptospira spp.	Water	Increased temperatures may increase range	Medium	Bharti *et al.*, 2003; Howell and Cole, 2006
		Increased precipitation and run off precedes outbreaks	High	Meites *et al.*, 2004
Viruses				
Enteroviruses	Water	Potential increase in temperature associated with increased peak clinical season (summer)	Low[d]	
		Increase in temperature associated with increased decay and inactivation of viruses in the environment	Medium	Gantzer *et al.*, 1998; Wetz *et al.*, 2004
		Increased precipitation associated with increased loading of viruses to water and increased disease	High	Lipp *et al.*, 2001a; Frost *et al.*, 2002; Fong *et al.*, 2005
Norovirus	Food	Increased temperature leads to decreased retention of virus in shellfish	Low[e]	Burkhardt and Calci, 2000
		Increased precipitation associated with increased loading of viruses to crops and fresh produce	Medium[b]	Miossec *et al.*, 2000
	Water	Increase in temperature associated with increased decay and inactivation of	Medium	Griffin *et al.*, 2003

		viruses in the environment		
		Increased precipitation associated with increased loading of viruses to water and increased disease	High	Goodman *et al.*, 1982
		Increase in temperature associated with shorter peak clinical season (winter)	Low[e]	
Rotavirus	Water	Increase in temperature associated with increased decay and inactivation of viruses in the environment	Medium	Rzezutka and Cook, 2004
Parasites				
Naegleria fowleri	Water	Increased temperature associated with expanded range and conversion to flagellated form (infective)	Medium[b]	Cabanes *et al.*, 2001
Cryptosporidium	Water	Increased precipitation associated with increased loading of parasite to water and increased disease	High[f]	Curriero *et al.*, 2001; Davies *et al.*, 2004
Giardia	Water	Increased temperature associated with shifting range in reservoir species (carriers) and expanded disease range	Medium[b]	Parkinson and Butler, 2005
		Increased precipitation associated with increased loading of parasite to water and increased disease	High[f]	Kistemann *et al.*, 2002

[a] Based on both research reports and likelihood of the event This confidence scale is based on conditional probabilities such that low represents an occurrence of <5/10, medium 5-6/10, high 8/10 and very high >9/10.

[b] Likelihood of event is probable but little research has addressed the issue

[c] Evidence is highly supportive but adaptive measures (refrigeration) would reduce this effect

[d] Geographical evidence supports this (infections show little seasonality near the equator) but no data are available

[e] There is no evidence for direct control of temperature on seasonality of infection

[f] Evidence is highly supportive but adaptive measures (water treatment and infrastructure) would reduce this effect

Air Quality

The sources and conditions that give rise to elevated ozone and PM2.5 in outdoor air in the U.S. have been and will continue to be affected by global environmental changes, related to land use, economic development, and climate change. Conversions of farmland and forests into housing developments and the infrastructure of schools and businesses that support them change the spatial patterns and absolute amounts of emissions from fuel combustion related to transportation, space heating, energy production, and other activities. Resulting vegetation patterns affect biogenic volatile organic compound (VOC) emissions that influence ozone production. Conversion of land from natural to man-made also changes the degree to which surfaces absorb solar energy (mostly in the form of light) and later re-radiate that energy as heat, which contributes to urban heat islands. In addition to their potential for increasing heat-related health effects, heat islands also can influence local production and dispersion of air pollutants like ozone and PM2.5.

The influence of meteorology on air quality is substantial and well-established (EPRI, 2005), suggesting that changes in climate could alter patterns of air pollution concentrations. Temperature and cloud cover affect the chemical reactions that lead to ozone and secondary particle formation. Winds, vertical mixing, and rainfall patterns influence the movement and dispersion of pollutants in the atmosphere. The most severe U.S. air pollution episodes occur with atmospheric conditions that limit both vertical and horizontal dispersion over multi-day periods. Climate change will alter the temporal and spatial distributions of meteorologic factors, which could influence air quality. Methods used to study the influence of climatic factors on air quality range from statistical analyses of empirical relationships to integrated modeling of future air quality resulting from climate change. To date, most studies have been limited to climatic effects on ozone concentrations. Though of great concern from a human health perspective, little research to-date has addressed climate impacts on anthropogenic particulate matter concentrations.

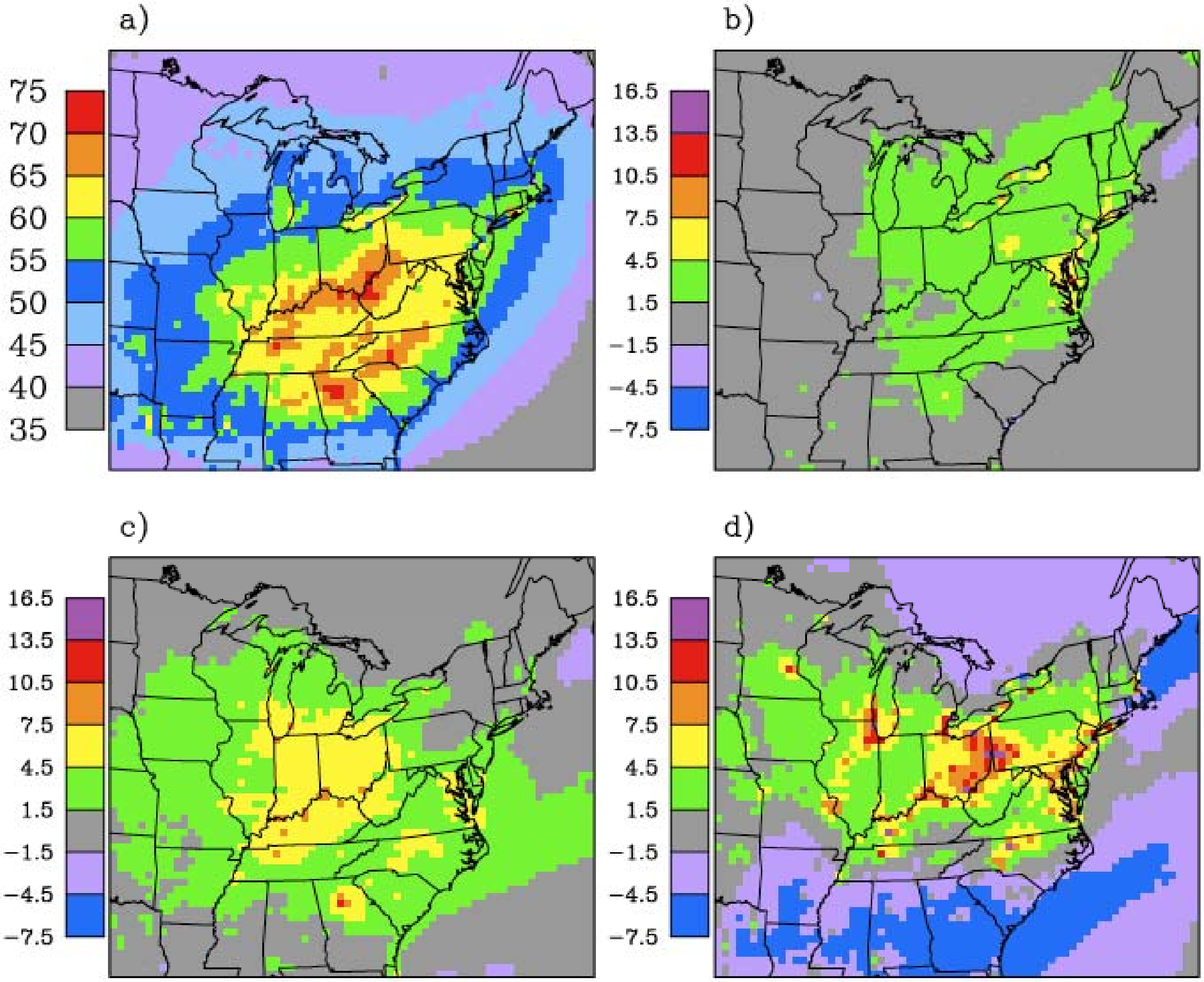
Leung and Gustafson (2005) used regional climate simulations for temperature, solar radiation, precipitation, and stagnation/ventilation, and projected worse air quality in Texas and better air quality in the Midwest in 2045-2055 compared with 1995-2005. Aw and Kleeman (2003) simulated an episode of high air pollution in southern California in

1996 with observed meteorology and then with higher temperatures. Ozone concentrations increased up to 16% with higher temperatures, while the PM2.5 response was more variable due to opposing forces of increased secondary particle formation and more evaporative losses from nitrate particles. Bell and Ellis (2004) showed greater sensitivity of ozone concentrations in the Mid-Atlantic to changes in biogenic than to changes in anthropogenic emissions. Ozone's sensitivity to changing temperatures, absolute humidity, biogenic VOC emissions, and pollution boundary conditions on a fine-scale (4 km grid resolution) varied in different regions of California (Steiner *et al.*, 2006).

Several studies explored the impacts of climate change alone on future ozone projections. In a coarse-scale analysis of pollution over the continental U.S., Mickley *et al.* (2004) used the GISS (NASA Goddard Institute for Space Studies) 4x5º model to project that, due to climate change alone (A1b emission scenario), air pollution could increase in the upper Midwest due to decreases between 2000 and 2052 in the frequency of Canadian frontal passages that clear away stagnating air pollution episodes. The 2.8x2.8º Mozart global chemistry/climate model was used to explore global background and urban ozone changes over the 21st century in response to climate change, with ozone precursor emissions kept constant at 1990s levels (Murazaki and Hess, 2006). While global background decreased slightly, the urban concentrations due to U.S. emissions increased.

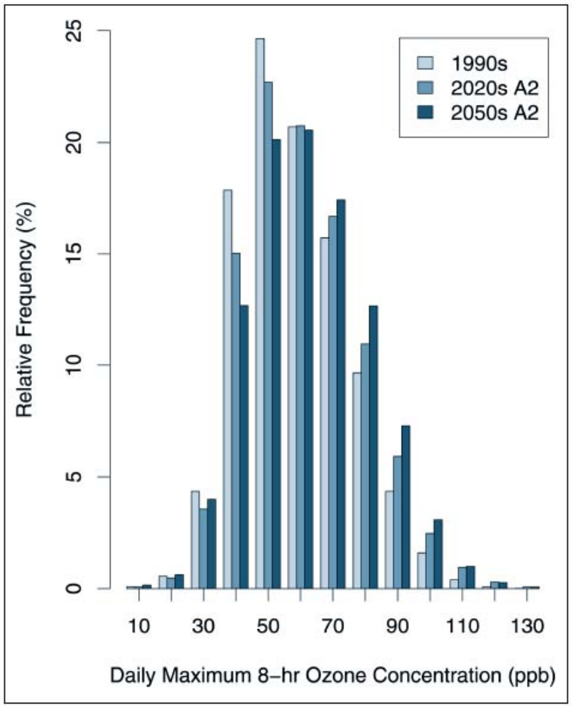
As part of the New York Climate and Health Study, Hogrefe and colleagues conducted local-scale analyses of air pollution impacts of future climate changes using integrated modeling (Hogrefe *et al.*, 2004a,b,c; 2005a,b) to examine the impacts of climate and land use changes on heat- and ozone-related health impacts in the NYC metropolitan area (Knowlton *et al.*, 2004; Kinney *et al.*, 2006; Bell *et al.*, 2007; Civerolo *et al.*, 2006). The GISS 4x5º was used to simulate hourly meteorologic data from the 1990s through the 2080s based on the A2 and B2 SRES scenarios. The A2 scenario assumes roughly double the CO2 emissions of B2. The global climate outputs were downscaled to a 36 km grid over the eastern U.S. using the MM5 regional climate model. The MM5 results were used in turn as inputs to the CMAQ regional-scale air quality model. Five summers (June, July, and August) in each of four decades (1990s, 2020s, 2050s, and 2080s) were simulated at the 36 km scale. Pollution precursor emissions over the eastern U.S. were based on U.S. EPA estimates at the county level for 1996. Compared with observations from ozone monitoring stations, initial projections were consistent with ozone spatial and temporal patterns over the eastern U.S. in the 1990s (Hogrefe *et al.*, 2004a). Average daily maximum 8-hour concentrations were projected to increase by 2.7, 4.2, and 5.0 ppb in the 2020s, 2050s, and 2080s, respectively due to climate change (Figure 4) (Hogrefe *et al.*, 2004b). The influence of climate on mean ozone values was similar in magnitude to the influence of rising global background by the 2050s, but climate had a much greater impact on extreme values than did the global background. When biogenic VOC emissions were allowed to increase in response to warming, an additional increase in ozone concentrations was projected that was similar in magnitude to that of climate alone (Hogrefe *et al.*, 2004b). Climate change shifted the distribution of ozone concentrations towards higher values, with larger relative increases in future decades (Figure 5).

Figure 4: (a) Summertime Average Daily Maximum 8-hour Ozone Concentrations (ppb) for the 1990s and Changes for the (b) 2020s, (c) 2050s, and (d) 2080s Based on the A2 Scenario Relative to the 1990s. Five consecutive summer seasons were simulated in each decade.



Source: Hogrefe et al., 2004a.

Figure 5. Frequency Distributions of Summertime Daily Maximum 8-hr Ozone Concentrations over the Eastern U.S. in the 1990s, 2020s, and 2050s based on the A2 Scenario.



Source: From Hogrefe *et al.*, 2005a

Projections in Germany also found larger climate impacts on extreme ozone values (Forkel and Knoche, 2006). Using the IS92a business-as-usual scenario, the ECHAM4 GCM projected changes for the 2030s compared with the 1990s; the output was downscaled to a 20 km grid using a modification of the MM5 regional model, which was in-turn linked to the RADM2 ozone chemistry model. Both biogenic VOC emissions and soil NO emissions were projected to increase as temperatures rose. Daily maximum ozone concentrations increased by between 2 and 6 ppb (6-10%) across the study region. However, the number of cases where daily maximum ozone exceeded 90 ppb increased by nearly four-fold, from 99 to 384.

Using the NYCHP integrated model, PM2.5 concentrations are projected to increase with climate change, with the effects differing by component species, with sulfates and primary PM increasing markedly and with organic and nitrated components decreasing, mainly due to movement of these volatile species from the particulate to the gaseous phase (Hogrefe *et al.*, 2005b; 2006).

Hogrefe *et al.*, 2005b noted that “the simulated changes in pollutant concentrations stemming from climate change are the result of a complex interaction between changes in transport, mixing, and chemistry that cannot be parameterized by spatially uniform linear regression relationships.” Additional uncertainties include how population vulnerability, mix of pollutants, housing characteristics, and activity patterns may differ in the future. For example, in a warmer world, more people may stay indoors with air conditioners in the summer when ozone levels are highest, decreasing personal exposures. Baseline mortality rates may change due to medical advances, changes in other risk factors such as smoking and diet, and aging of the population.

The New York Climate and Health Project examined the marginal sensitivity of health to changes in climate to project the potential health impacts of ozone in the eastern U.S. (Knowlton *et al.*, 2004; Bell *et al.*, 2007). Knowlton and colleagues computed absolute and percentage increases in ozone-related daily summer-season deaths in the NYC metropolitan region in the 2050s as compared with the 1990s using a downscaled GCM/RCM/air quality model (Knowlton *et al*., 2004; Kinney *et al.*, 2006). The availability of county-scale ozone projections made it possible to compare impacts in the urban core with those in outlying areas. Increases in ozone-related mortality due to climate change ranged from 0.4 to 7.0% across 31 counties. Bell and colleagues expanded the analysis to 50 eastern cities and examined both mortality and hospital admissions (Bell *et al.*, 2007). Average ozone concentrations were projected to increase by 4.4 ppb (7.4%) in the 2050s; the range was 0.8% to 13.7%. Changes in health impacts were of corresponding magnitude.

Based on the new research findings published since the previous assessment, the following summary statements can be made:

- Both ozone and fine particle concentrations are likely to be affected by climate change.
- A substantial body of new evidence on ozone supports the interpretation that ozone concentrations will tend to increase in the U.S. as a result of climate change, all else being equal.
- Too few data yet exist for PM to draw firm conclusions about the direction or magnitude of climate impacts.

Vulnerable Subpopulations

"Vulnerability" is defined as the summation of all risk and protective factors that ultimately determine whether a subpopulation experiences adverse health outcomes, and "sensitivity" is defined as an individual's or subpopulation's increased responsiveness, primarily for biological reasons, to a given exposure. Specific subpopulations may experience heightened vulnerability for climate-related health effects for a wide variety of reasons. Biological sensitivity may be related to the presence of pre-existing chronic medical conditions (such as the sensitivity of people with chronic heart conditions to heat-related illness), developmental stage, acquired factors (such as immunity), and genetic factors (such as metabolic enzyme subtypes that play a role in vulnerability to air pollution effects). Socioeconomic factors also play a critical role in altering vulnerability and sensitivity to environmentally-mediated factors. They may increase likelihood of exposure to harmful agents, interact with biological factors that mediate risk (such as nutritional status), and/or lead to differences in the ability to adapt or respond to exposures or early phases of illness and injury. For public health planning, it is critical to recognize populations that may experience synergistic effects of multiple risk factors for health problems, both related to climate change and related to other temporal trends.

Certain regions of the United States may experience increased risks for specific climate-sensitive health outcomes due to their baseline climate, abundance of natural resources such as fertile soil and fresh water supplies, elevation, or vulnerability to coastal surges or riverine flooding. Some regions may in fact experience multiple climate-sensitive health problems simultaneously.

An initial approach to identifying subpopulations with heightened vulnerability to climate-sensitive health outcomes is to consider the biological and socioeconomic risk factors for each health outcome (Table 3).

Table 3. Climate-Sensitive Health Outcomes and Particularly Vulnerable Groups

Climate Sensitive Health Outcome	Particularly Vulnerable Groups
Heat Stress	Elderly, chronic medical conditions, infants and children, pregnant women, urban and rural poor, outdoor workers
Air Pollution	Children, pre-existing heart or lung disease, diabetes, athletes and outdoor workers
Extreme Weather Events	Poor, pregnant women, those with chronic medical conditions, and mobility and cognitive constraints
Water- and Foodborne Illness	Immunocompromised, elderly, infants; specific risks for specific consequences (e.g., *Campylobacter* and Guillain-Barre syndrome, *E. coli* O157:H7)
Vectorborne Illness	
A. Lyme Disease	Outdoor workers
B. Hantavirus	Rural poor, occupational groups
C. Dengue	Infants, elderly
D. Malaria	Immunocompromised, pregnancy genetic (G6PD status)

Children

Children’s small body mass to surface area ratio and other factors make them more vulnerable to heat-related morbidity and mortality (AAP, 2000), while their increased breathing rates relative to body size, time spent outdoors and developing respiratory tracts heighten their sensitivity to harm from ozone air pollution (AAP, 2004). In addition, children's relatively naïve immune systems increase the risk of serious consequences from water and foodborne diseases; specific developmental factors make them more vulnerable to complications from specific severe infections like E Coli O157:H7. Children may also be more vulnerable to psychological complications of extreme weather events related to climate change. Following two floods in Europe in the 1990s, children demonstrated moderate to severe stress symptoms (Becht *et al.*, 1998; cited in Hajat *et al.*, 2003) and long-term PSTD, depression, and dissatisfaction with ongoing life (Bokszanin, 2000; cited in Hajat *et al.*, 2003).

Pregnant women

Pregnant women are likely to be vulnerable to adverse health effects in the aftermath of extreme weather events, problems, including exposure to environmental toxins, limited access to safe food and water, psychological stress, and disrupted health care access. One review suggested increased incidence of adverse reproductive outcomes after Hurricane Katrina (Callaghan *et al.*, 2007). Pregnancy also confers increased susceptibility to a variety of climate-sensitive infectious diseases, including malaria and foodborne infections (Jamieson *et al.*, 2006).

Older Adults

Health effects associated with climate change pose significant risks for the elderly, who often have frail health and limited mobility. Older adults are more sensitive to temperature extremes, particularly heat (Semenza *et al.*, 1996; Medina-Ramon *et al.*, 2006); individuals 65 years of age and older comprised 72% of the heat-related deaths in the 1995 Chicago heatwave (Whitman *et al.*, 1997). The elderly are also more likely to have preexisting medical conditions, including cardiovascular and respiratory illnesses, which may put them at greater risk of exacerbated illness by climate-related events or conditions. For example, a 2004 rapid needs assessment of older adults in Florida found that Hurricane Charley exacerbated preexisting, physician-diagnosed medical conditions in 24-32% of elderly households (CDC, 2004). Effects of ambient particulate matter on daily mortality tend to be greatest in older age groups (Schwartz, 1995).

Impoverished Populations

Even in the U.S., the greatest health burdens will likely to fall on those with the lowest socioeconomic status (O'Neill *et al.*, 2003a). Most affected are individuals with inadequate shelter or resources to find alternative shelter in the event their community is disrupted. While quantitative methods to assess the increase in risk related to these social and economic factors are not well-developed, qualitative insights can be gained by examining risk factors for mortality and morbidity from recent weather-related extreme events such as the 1995 heatwave in Chicago and Hurricane Katrina in 2005.

Studies of heatwaves identify poor housing conditions, including lack of access to air conditioning and living spaces with fewer rooms, as significant risk factors for heat-related mortality (Kalkstein, 1993; Semeza *et al.*, 1996). Higher heat-related mortality has been associated with socioeconomic indicators, such as lacking a high school education and living in poverty (Curriero *et al.*, 2002). Financial stress plays a role, as one study of the 1995 Chicago heatwave found that concern about the affordability of utility bills influenced individuals to limit air conditioning use (Klinenberg, 2002). The risk for exposure and sensitivity to air pollution is also elevated among groups in a lower socioeconomic position (O'Neill *et al.*, 2003a).

Box 1: Hurricane Katrina

In 2005, Hurricane Katrina caused more than 1,500 deaths along the Gulf Coast, and many of these victims were members of vulnerable populations, such as hospital and nursing-home patients, older adults who required care within their homes, and individuals with disabilities (U.S. CHSGA, 2006). According to the Louisiana Department of Health and Hospitals, more than 45% of the state's identified victims were 75 years of age or older; 69% were above age 60 (LDHH, 2006). In Mississippi, 67% of the victims whose deaths were directly, indirectly, or possibly related to Katrina were 55 years of age or older (MSDH, 2005).

At hurricane evacuation centers in Louisiana, Mississippi, Arkansas, and Texas, chronic illness was the most commonly reported health problem, accounting for 33% or 4,786 of 14,531 visits (CDC, 2006b). A quarter of the deaths indirectly related to the hurricane in Alabama were associated with preexisting cardiovascular disease (CDC, 2006d), and the storm disrupted an estimated 100,000 diabetic evacuees across the region from obtaining appropriate care and medication (Cefalu *et al.*, 2006). One study suggested that the hurricane had a negative effect on reproductive outcomes among pregnant women and infants, who experienced exposure to environmental toxins, limited access to safe food and water, psychological stress, and disrupted health care (Callaghan *et al.*, 2007). Other vulnerable individuals included those without personal means of transportation and poor residents in Louisiana and Mississippi who were unable to evacuate in time (U.S. CHSGA, 2006).

The tragic loss of life that occurred after Hurricane Katrina underscores the increased vulnerability of special populations and demonstrates that, in the wake of extreme weather events, particularly those that disrupt medical infrastructure and require large-scale evacuation, treating individuals with chronic diseases is of critical concern (Ford *et al.*, 2006).

People with chronic conditions and mobility and cognitive constraints

People with chronic medical conditions have an especially heightened vulnerability for the health impacts of climate change. Extreme heat poses a great risk for individuals with diabetes (Schwartz, 2005), and extreme cold has an increased effect on individuals with chronic obstructive pulmonary disease (Schwartz, 2005). People with mobility and cognitive constraints may be at particular risk during heat waves and other extreme weather events (EPA, 2006). As noted above, people with chronic medical conditions are also at risk of worsened status as the result of stressors and limited access to medical care during extreme events.

Occupational groups

Certain occupational groups, primarily by virtue of spending their working hours outdoors, are at greater risk of climate-related health outcomes. Outdoor workers in rural or suburban areas, such as electricity and pipeline utility workers, are at increased risk of Lyme Disease (Schwartz and Goldstein, 1990; Piacentino and Schwartz, 2002). They and other outdoor workers have increased exposures to ozone air pollution and heat stress, especially if work tasks involve heavy exertion.

Table 4 summarizes the climate-related vulnerability of specific U.S. subpopulations, based on age, underlying medical conditions, and socioeconomic status. Recognition of combined effects will aid efforts at public health intervention and disease prevention.

Table 4. Summary of Vulnerability to Climate-Sensitive Health Outcomes by Subpopulation

Groups with Increased Vulnerability	Climate-Related Vulnerabilities
Infants and Children	Heat stress, ozone air pollution, waterborne and foodborne illnesses, dengue, malaria
Pregnant women	Heat stress, extreme weather events, water and foodborne illnesses, malaria
Elderly / chronic medical conditions	Heat stress, air pollution, extreme weather events, water and foodborne illnesses, dengue
Impoverished / low socioeconomic status	Heat stress, extreme weather events, air pollution, vector-borne infectious diseases
Outdoor workers	Heat stress, ozone air pollution, Lyme disease, other vector-borne infectious diseases.

3.4 Priority Research Needs and Data Gaps

Few research needs and data gaps have been filled since the First National Assessment. An important shift in perspective that occurred since the first National Assessment is a great appreciation of the complex pathways by which weather and climate affect health, and the understanding that many non-climatic, social, and behavioral factors will influence disease risks and patterns (NRC, 2001). Several research gaps identified in the First National Assessment have been partially filled by studies that address the differential effects of temperature extremes by community, demographic, and biological characteristics; that improve our understanding of exposure-response relationships for extreme heat; and that project the public health burden posed by climate-related changes in heatwaves and air pollution. Despite these advances, the body of literature remains small, limiting quantitative projections of future impacts. Considerably more research is needed to ensure the U.S. is adequately prepared to cope with projected changes in climate.

Research needs can be classified into:

- Increase understanding of exposure-response relationships, including identifying likely thresholds and particularly vulnerable groups, taking into consideration relevant factors that affect the geographic range and incidence of climate-sensitive health outcomes, including disease ecology and transmission dynamics. Research on morbidity relationships is particularly needed. Long-term data collection is needed, focusing on regions and populations likely to be particularly vulnerable. Also need are:

- Empirical studies to quantify the independent and joint effects of air pollution and weather on morbidity and mortality, with explicit evaluation of effect modification.
- Studies to quantify and better understand the adaptive response to heat stress.
- Evidence for early effects of changing weather patterns on climate-sensitive health outcomes.
- Surveillance systems targeted towards emerging infectious diseases, particularly those related to insect and animal vectors.
- Quantitative models of the possible health impacts of climate change that can be used to explore a range of socioeconomic and climate scenarios.
- Studies that model the two-way interactions of climate and air quality at global and regional scales.
- Studies that incorporate a full suite or “ensemble” of climate models and scenarios to examine potential future impacts.
- Increase understanding of the process of adaptation, including the costs of those interventions. For example, heatwave and health early warning systems are not inspiring appropriate behavior; further research is needed to understand how messages can be made more effective.
- Evaluation of adaptation measures. For example, evaluation of heatwave and health early warning systems, especially as they become implemented on a wider scale (NOAA, 2005), is needed to understand how to motivate appropriate behavior.
- Adaptation models to better understand the benefits and limits of specific policies and measures; and
- Comprehensive estimates of the co-benefits of mitigation policies. Methods to incorporate both direct health benefits as well as GHG mitigation benefits into local land use decisions.

In addition, policymakers need local and regional scale vulnerability and adaptation assessments to understand the potential risks and the time horizon over which those risks might arise; these assessments should include stakeholders to ensure their needs are identified and incorporated into subsequent research and adaptation activities.

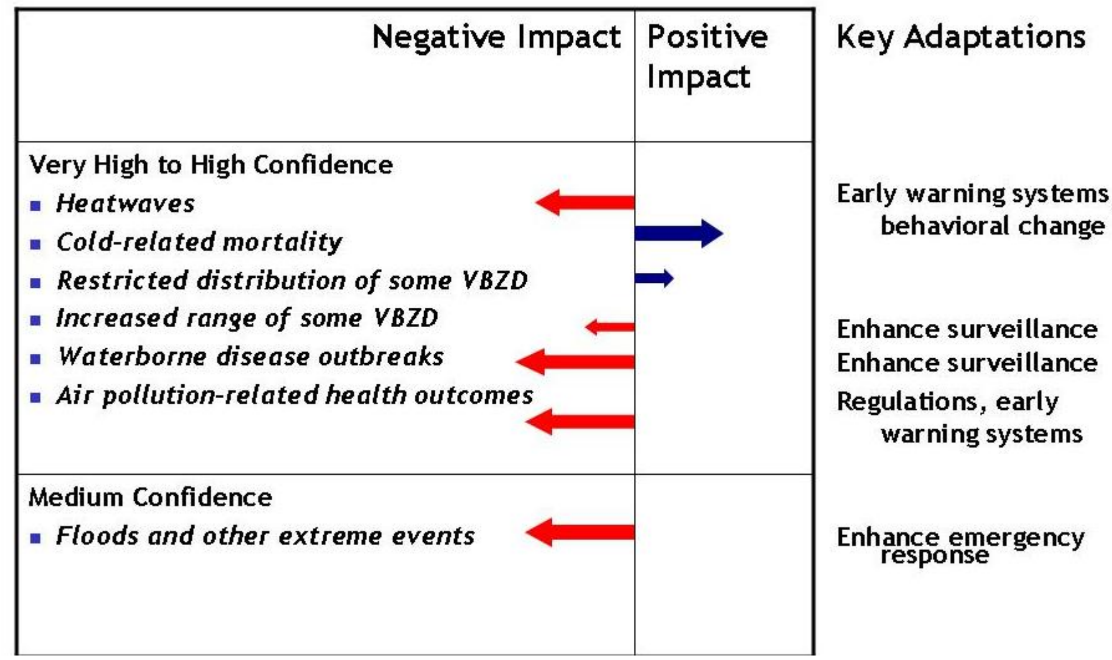
For extreme weather events, heatwaves, and food- and waterborne diseases, investments in infrastructure may be needed in some regions to provide protection against extreme events, to alter urban design to decrease heat islands, and to maintain drinking and wastewater treatment standards and source water and watershed protection.

Underlying these needs are requirements for long-term data collection on issues of potential concern, such as surveillance of the geographic range of vectorborne and zoonotic diseases, and better surveillance and reporting of food- and waterborne diseases. Downscaled climate projections to local and regional levels are needed. The growing concern over impacts from extreme events means that climate models are needed for stochastic generation of possible future events, to assess not only how disease and pathogen population dynamics might respond, but also to assess whether levels of preparedness are likely to be adequate.

Conclusions

The conclusions from this assessment are consistent with those of the first National Assessment: climate change poses a risk for U.S. populations, with uncertainties limiting quantitative projections of the number of increased injuries, illnesses, and deaths attributable to climate change. However, the strength and consistency of projections for climatic changes for some exposures of concern to human health suggest that adaptation actions are needed now. Further, trends in factors that affect vulnerability, such as a larger and older U.S. population, will increase overall vulnerability to health risks. At the same time, the capacity of the U.S to implement effective and timely adaptation measures is assumed to remain high throughout this century, thus reducing the likelihood of severe health impacts. However, the nature of the risks posed by climate change mean that all adverse health outcomes will not be avoided. Figure 6 provides a qualitative summary of the relative direction, magnitude, and certainty of health impacts.

Figure 6: Summary of Relative Direction, Magnitude, and Certainty of Health Impacts



3.5 Adaptation

Realistically assessing the potential health effects of climate change must include consideration of the capacity to manage new and changing climatic conditions. Individuals, communities, governments, and other organizations currently engage in a wide range of actions to identify and prevent adverse health outcomes associated with weather and climate. Although these actions have been largely successful, recent extreme events and outbreaks of vectorborne diseases highlight areas for improvement. Further, as detailed in Part 1 of this chapter, climate change is likely to challenge the ability of current programs and activities to control climate-sensitive health determinants and outcomes. Preventing additional morbidity and mortality requires developing and deploying adaptation policies and measures that include specific consideration of the full range of health risks that are likely to arise with climate change.

In public health, prevention is the term analogous to adaptation. Public health prevention is classified as primary, secondary, or tertiary. Primary prevention aims to prevent the onset of disease in an otherwise unaffected population (such as regulations to reduce harmful exposures to ozone). Secondary prevention entails preventive action in response to early evidence of health effects (including strengthening disease surveillance programs to provide early intelligence on the emergence or re-emergence of health risks at specific locations and responding effectively to disease outbreaks, such as West Nile virus). Tertiary prevention consists of measures (often treatment) to reduce long-term impairment and disability and to minimize suffering caused by existing disease. In general, primary prevention is more effective and less expensive than secondary and tertiary prevention. For every health outcome, there are multiple possible primary, secondary, and tertiary preventions.

The degree to which programs and measures will need to be modified to address the additional pressures due to climate change will depend on factors such as the current burden of climate-sensitive health outcomes, the effectiveness of current interventions, projections of where, when, and how quickly the health burdens could change with changes in climate and climate variability (which depends on the rate and magnitude of climate change), the feasibility of implementing additional cost-effective interventions, other stressors that could increase or decrease resilience to impacts, and the social, economic, and political context within which interventions are implemented (Ebi *et al.*, 2006a). Although there are uncertainties about future climate change, failure to invest in adaptation may leave communities poorly prepared and increase the probability of severe adverse consequences (Haines *et al.*, 2006a,b).

Climate change is basically a risk management issue. Adaptation and mitigation are the primary responses to manage current and projected risks. Mitigation and adaptation are not mutually exclusive; co-benefits to human health can result concurrently with implementation of mitigation actions. A public dialogue is needed on prioritizing the costs of mitigation actions designed to limit future climate change and the potential costs of continually trying to adapt its impacts. This dialogue should explicitly recognize that there is no guarantee that future changes in climate will not present a threshold that poses technological or physical limits to which adaptation is not possible.

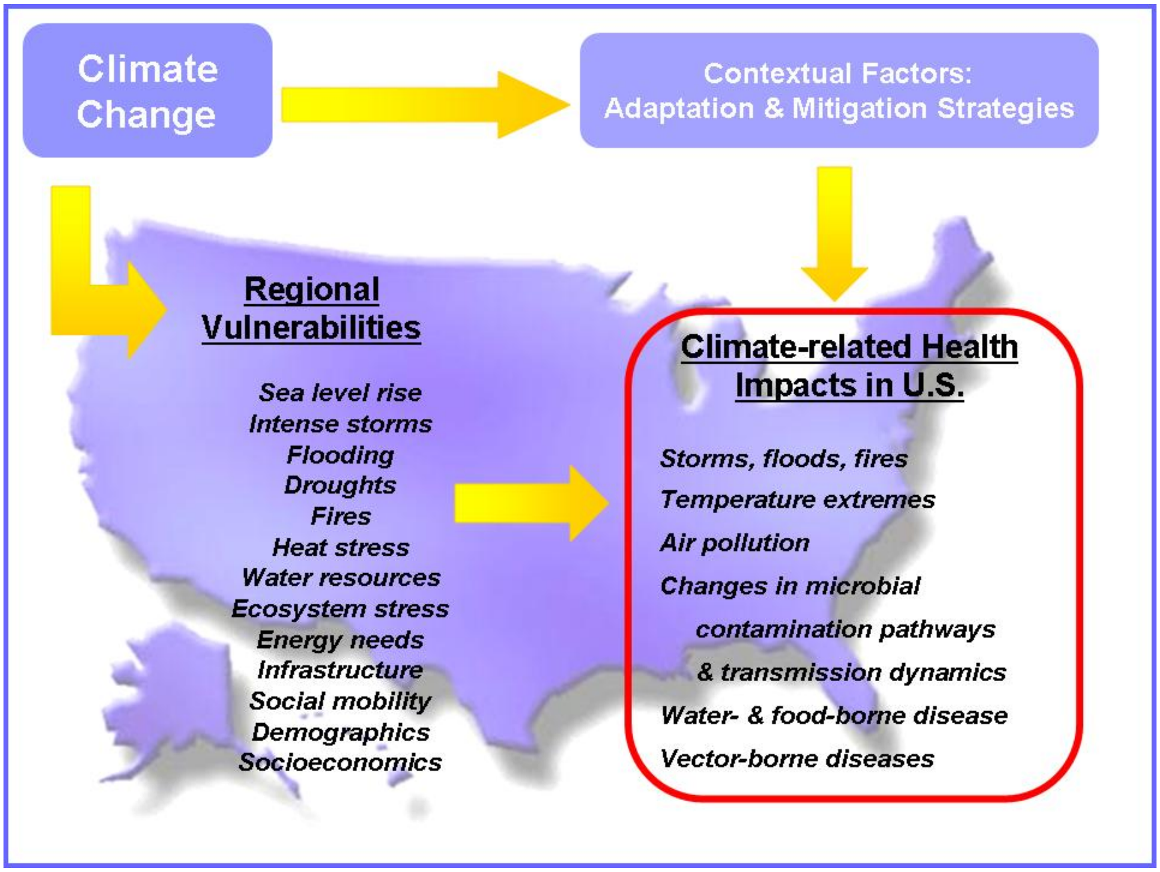
Adaptation policies and measures should address both projected risks and the regions and populations that currently are not well adapted to climate-related health risks. Because the degree and rate of climate change is projected to increase over time, adaptation will be a continual process attempting to prevent adverse impacts from changing exposures and vulnerabilities. History suggests that this process will likely be a step-function, with occasional large impacts (although these events can not be attributed to climate change, illustrative examples include Hurricane Katrina or the appearance and spread of West Nile virus) followed by changes in public health and other programs and practices to reduce future vulnerability. Obviously, the extent to which effective proactive adaptations are developed and deployed will be a key determinant of future morbidity and mortality attributable to climate change.

This section focuses on adaptation to the potential health impacts of environmental change in the United States, and considers actors and their roles and responsibilities for adaptation, and adaptation measures to reduce projected climate change-related health risks.

Framework for Adaptation

Figure 7 provides a framework for adaptation. Adaptation activities take place within the context of slowly-changing factors that are partial determinants of the extent of impacts experienced and that are specific to a region or population, including specific population and regional vulnerabilities, social and cultural factors, the built and natural environment, the status of the public health infrastructure, and health and social services. Because these factors vary across geographic and temporal scales, adaptation policies and measures generally are more successful when focused on a specific population and location. Other factors that set the context within which adaptation measures are designed and implemented include the degree of risk perceived, the human and financial resources available for adaptation, the available technological options, and the political will to undertake adaptation.

Figure 7: Framework for Adaptation



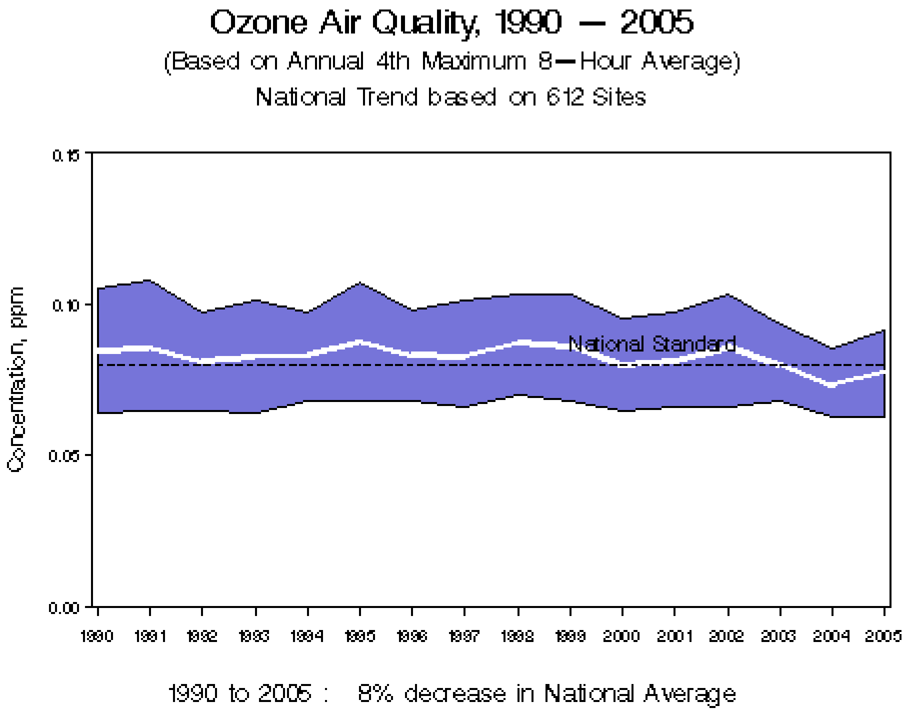
Actors and Their Roles and Responsibilities for Adaptation

Responsibility for the prevention of climate-sensitive health risks rests with individuals, community and state governments, national agencies, and others. The roles and responsibilities vary by health outcome (see example in Box 2). For example, individuals are responsible for taking appropriate action on days with declared poor air quality, with health care providers and others responsible for providing the relevant information, and government agencies providing the regulatory framework. Community governments play a central role in preparedness and response for extreme events because of their jurisdiction over police, fire, and ambulatory services and through emergency preparedness plans (Box 3). Early warning systems for extreme events and outbreaks of infectious diseases may be developed at the community or state level. The federal government funds research and development to increase the range of decision support tools (Box 4). Medical and nursing schools are responsible for ensuring that health professionals are trained in the identification and treatment of climate-sensitive diseases. The Red Cross and other nongovernmental organizations (NGOs) often play critical roles in disaster response.

Box 2: Ensuring Safe Air and Drinking Water

The U.S. EPA is tasked with establishing and enforcing regulations to ensure the nation has safe air and drinking water. The Clean Air Act of 1990 requires EPA to set National Ambient Air Quality Standards for pollutants considered to be harmful to public health and the environment. There are two types of standards: primary standards that protect public health, including the health of sensitive populations, such as asthmatics and elderly citizens. Secondary standards set limits to protect public welfare. The six criteria air pollutants include ozone, nitrogen dioxide, and sulfur oxides. The ozone standard is currently under review. As shown in Figure 8, national concentrations of ozone decreased 8% decreased from 1990 to 2005 (www.epa.gov/airtrends/ozone.html), with large variability in local trends. Because climate change may increase ozone concentrations in some regions, more aggressive emissions controls may be needed to reduce ozone concentrations.

Figure 8: Ozone Air Quality, 1990-2005



Source: http://www.epa.gov/airtrends/ozone.html, accessed 12 February 2007

Box 3: Heatwave early warning systems

Projections for increases in the frequency, intensity and duration of heatwaves suggests more cities need heatwave early warning systems, including forecasts coupled with effective response options, to warn the public about the risks during such events (Meehl and Tebaldi 2004). Prevention programs designed to reduce the toll of hot weather on the public have been instituted in several cities, and guidance has been developed to further aid communities seeking to plan such interventions, including buddy systems, cooling centers, and community preparedness (EPA 2006b). Although these systems appear to reduce the toll of hot weather (Ebi et al. 2004; Ebi and Schmier 2005; Weisskopf et al. 2002), a survey of individuals 65 or older in four North American cities (Dayton, OH; Philadelphia, PA; Phoenix, AZ; and Toronto, Ontario, Canada) found that the public was unaware of appropriate preventive actions to take during heatwaves (Sheridan 2006). Although respondents were aware of the heat warnings, the majority did not consider they were vulnerable to the heat, or did not consider hot weather to pose a significant danger to their health. Only 46% modified their behavior on the heat advisory days. Although many individuals surveyed had access to home air-conditioning, their use of it was influenced by concerns about energy costs. Precautionary steps recommended during hot weather, such as increasing intake of liquids, were taken by very few respondents (Sheridan 2006). Some respondents reported using a fan indoors with windows closed and no air-conditioning, a situation that can increase heat exposure and be potentially deadly. Further, simultaneous heat warnings and ozone alerts were a source of confusion, because recommendations not to drive conflicted with the suggestion to seek cooler locations if the residence was too warm. Critical evaluation is needed of heatwave early warning systems, including which components are effective and why (Kovats and Ebi 2006; NOAA 2005).

Box 4: Enhancing Surveillance for Mosquito-borne Diseases

Brownstein *et al.* (2004) is an example of recent research using GIS and other tools to facilitate surveillance and control of infectious diseases. In 2006, 1,419 West Nile virus (WNV) human cases, with 161 fatalities, were reported to the CDC from 45 states (http://www.cdc.gov/ncidod/dvbid/westnile/surv&controlCaseCount06_detailed.htm, accessed 12 February 2007). Although a national human surveillance system has been established, passive surveillance data are problematic because most cases of disease are relatively mild (so are unreported) and because of variability in disease reporting across counties and states. To improve targeting of prevention resources, Brownstein *et al.* (2004) developed a statistical method to estimate human disease risk early in the transmission season. Crude county-specific incidence rates were calculated in August 2003 based on weekly case numbers, and then random noise was removed. A conditional autoregressive model was then used to project counties that would experience a high incidence of WNV during 2003. Brownstein *et al.* (2004) also used their model to quantify the utility of nonhuman (e.g. bird and mosquito) surveillance. Quantitative mosquito data predicted 15-times more of the variation in human cases than quantitative bird data, emphasizing that active mosquito surveillance is the most sensitive marker of human risk. Unfortunately, not all states have effective active mosquito surveillance. This tool has the potential to identify high-risk counties before the major influx of cases during the transmission season, which would help target more effective disease prevention efforts.

Additional research and development are needed to ensure that surveillance systems account for and anticipate the potential effects of climate change. Surveillance systems will be needed in locations where changes in weather and climate may foster the spread of climate-sensitive pathogens and vectors into new regions (NAS, 2001). Understanding associations between disease patterns an environmental variables can be used to develop early warning systems that warn of outbreaks before most cases have occurred. Increased understanding is needed of how to design these systems where there is limited knowledge of the interactions of climate, ecosystems, and infectious diseases (NAS, 2001).

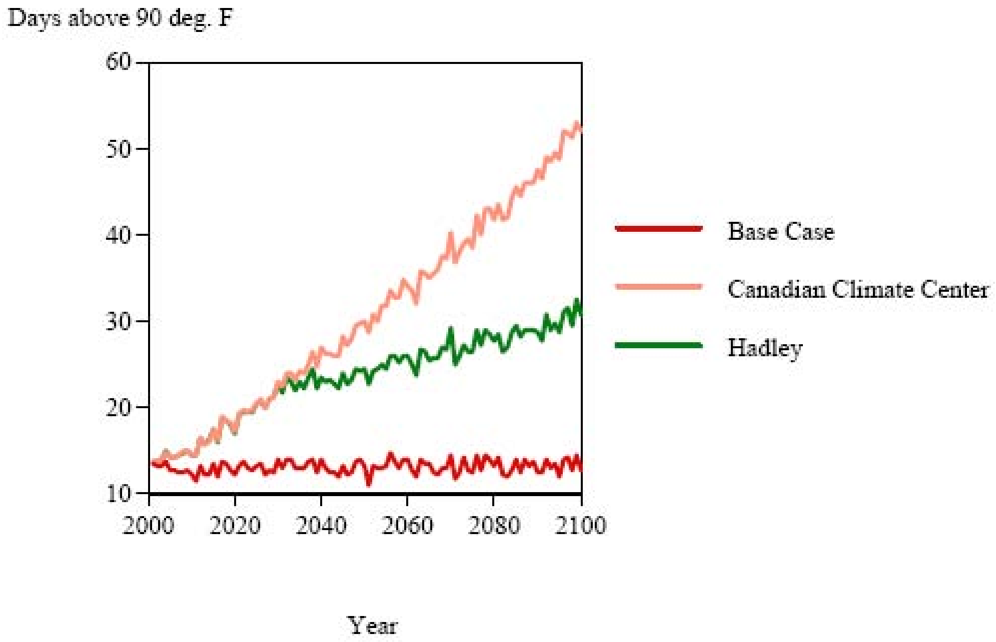
Surveys have not been conducted in the U.S. of the risk various actors responsible for coping with climate change-related health impacts. However, the growing numbers of city and state actions on climate change show increasing awareness of the potential risks. As of 1 February 2007, 393 cities representing 57 million Americans have signed the U.S. Mayors Climate Protection Agreement (http://www.seattle.gov/mayor/climate/cpaText.htm); although this agreement focuses on mitigation through increased energy efficiency, one strategy, planting trees, can both sequester CO2 and reduce urban heat islands. The New England Governors and Eastern Canadian Premiers developed a Climate Change Action Plan because of concerns about 'degradation in air quality and an increase in urban smog (with its associated human health impacts); public health risks; insect reproduction and the population of disease-bearing pests such as mosquitoes; the magnitude and frequency of extreme climatic phenomena' and availability of water (NEC/ECP, 2001). Action Item 7 focuses on the reduction and/or adaptation of negative social, economic, and environmental impacts. Activities being undertaken include a long-term phenology study, studies on temperature increases and related potential impacts, and the creation of a consortium of researchers and scientists.

Strategies, policies, and measures implemented by community and state governments, federal agencies, NGOs, and other actors can change the context for adaptation by sponsoring research and development to assess vulnerability (see Box 5) and to identify technological options available for adaptation, implementing programs and activities to reduce population vulnerability, and allocating human and financial resources to address the health impacts of climate change. State and federal governments also can provide guidance for vulnerability assessments that consider a range of plausible future scenarios. The results of these assessments can be used to identify priority health risks (over time), particularly vulnerable populations and regions, effectiveness of current adaptation activities, and modifications to current activities or new activities to implement to address current and future climate change-related risks. Adaptations should be designed to address projected health burdens.

Box 5: Projected Heat-Related Mortality in Metropolitan Boston (CLIMB, 2004)

An assessment was undertaken of metropolitan Boston's vulnerability to climate change-related temperature mortality. Analysis of temperature-mortality relationships for 1970-1998 identified 90ºF as the threshold above which mortality increased. A base climate case was created by using historical weather data to project regional temperatures to 2050, and then using a moving block bootstrapping method to project temperatures to 2100. Trends from two climate models (Canadian Climate Center and Hadley Centre) were superimposed on these projections to create time series data of future weather conditions that were consistent with past patterns and climate change trends. Figure 9 shows projected annual average number of days above 90ºF under the three scenarios.

Figure 9: Annual Average Number of Day above 90°F, Metropolitan Boston

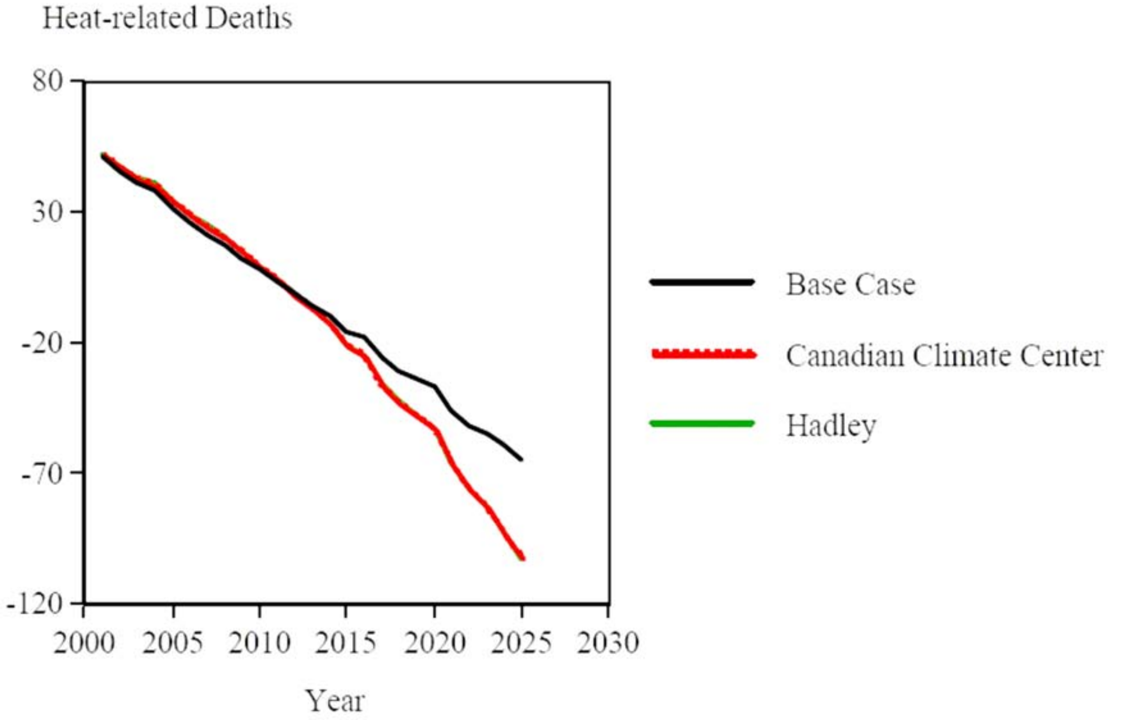


Source: CLIMB, 2004

A key adaptation assumption was that the observed approximate 50% decrease in heat-related mortality between 1970 and 1992 would continue. Figure 10 shows the projected annual heat-related deaths for metropolitan Boston under the three scenarios; a slight increase in mortality was projected until about 2010 under climate change, then a continual decline in mortality under all scenarios to 2100. The decline is more pronounced under the climate scenarios in which the frequency of extreme heatwaves increases, which was primarily due to assuming a continuation of historic trends in mortality declines.

This assessment highlights that even under assumptions of significant increases in adaptation, there may be short-term climate change-related increases in mortality. Taken at face value, these results suggest that metropolitan Boston is likely to be well adapted to future heat-related mortality. However, the observed decline in mortality includes increased use of air conditioning over the past 30 years, improvements in health care, and other changes. Continuing to achieve large reductions in heat-related mortality will require more aggressive efforts, such as implementing a heat early warning system and taking actions to reduce the urban heat island. Another factor to consider is that an aging population may be more susceptible to high temperatures. Overall, this assessment suggests the need for more adaptation.

Figure 10: Annual Heat-Related Mortality to 2030, Metropolitan Boston



Source: CLIMB, 2004

Table 5 summarizes the other roles and responsibilities of various actors for adapting to climate change. Note that viewing adaptation from a public health perspective results in similar activities being classified as primary vs secondary prevention under different health outcomes. It is not possible to prevent the occurrence of a heatwave, so primary prevention focuses on actions such as developing and enforcing appropriate infrastructure standards, while secondary prevention focuses on implementing early warning systems and other activities. For vectorborne diseases, primary prevention refers to preventing exposure to infected vectors; in this case, early warning systems can be considered primary prevention. For most vectorborne diseases, there are few options for preventing disease onset once an individual has been bitten. Vaccines are available for Lyme disease and are under development for others, such as West Nile virus.

A key activity not included in this framework is research on the associations between weather / climate and various health outcomes, taking into consideration other drivers of those outcomes (e.g. taking a systems-based approach), and projecting how those risks may change with changing weather patterns. Increased understanding of the human health risks posed by climate change is needed for the design of effective, efficient, and timely adaptation options.

Table 5: Actors and Their Roles and Responsibilities for Adaptation

Actor	Reduce Exposures	Prevent Disease Onset	Reduce Morbidity and Mortality
Extreme Temperature and Weather Events			
Individuals	Stay informed about impending weather events Follow guidance for emergency preparedness	Follow guidance for conduct during and following an extreme weather event (such as seeking cooling centers during a heatwave or evacuation during a hurricane)	Seek treatment when needed
Community, State, and National Agencies	Provide scientific and technical guidance for building and infrastructure standards Enforce building and infrastructure standards	Develop scientific and technical guidance and decisions support tools for development of early warning systems and emergency response plans, including appropriate individual behavior Implement early warning systems and emergency response plans Conduct tests of early warning systems and response plans before events Conduct education and outreach on emergency preparedness	Ensure that emergency preparedness plans include medical services Monitor the air, water, and soil for hazardous exposures Collect, analyze, and disseminate data on the health consequences of extreme events and heatwaves Monitor and evaluate the effectiveness of systems
NGOs and Other Actors		NGOs and other actors play critical roles in emergency preparedness and disaster relief	Education and training of health professionals on risks from extreme weather events
Vectorborne and Zoonotic Diseases			
Individuals	Take appropriate actions to reduce exposure to infected vectors, including eliminating vector breeding sites around residence	Vaccinate for diseases to which one would likely be exposed	Seek treatment when needed

Community, State, and National Agencies	Provide scientific and technical guidance and decisions support tools for development of early warning systems Institute and maintain effective vector (and pathogen) surveillance and control programs (including consideration of land use policies that affect vector distribution and habitats) Develop early warning systems for disease outbreaks, such as West Nile virus Develop and disseminate information on appropriate individual behavior to avoid exposure to vectors	Sponsor research and development on vaccines and other preventive measures Sponsor research and development on rapid diagnostic tools Provide low-cost vaccinations to those likely to be exposed	Sponsor research and development on treatment options Develop and disseminate information on signs and symptoms of disease to guide individuals on when to seek treatment
Waterborne and Foodborne Diseases			
Individuals	Follow proper food-handling guidelines Follow guidelines on drinking water from outdoor sources		Seek treatment when needed
Community, State, and National Agencies	Develop and enforce watershed protection and safe water and food handling regulations (e.g., Clean Water Act)	Sponsor research and development on rapid diagnostic tools for food- and waterborne diseases	Sponsor research and development on treatment options Develop and disseminate information on signs and symptoms of disease to guide individuals on when to seek treatment
Diseases Related to Air Pollution			
Individuals	Follow advice on appropriate	For individuals with certain respiratory	Seek treatment when needed

	behavior on high ozone days	diseases, follow medical advice during periods of high air pollution	
Community, State, and National Agencies	Develop and enforce regulations of air pollutants (e.g., Clean Air Act)	Develop scientific and technical guidance and decisions support tools for development and implementation of early warning systems Conduct education and outreach on the risks of exposure to air pollutants	Sponsor research and development on treatment options

Adaptation Measures to Manage Climate Change-Related Health Risks

Determining where populations are not effectively coping with current climate variability and extremes facilitates identification of the additional interventions that are needed now. However, given climate change projections, identifying current adaptation deficits is not sufficient to protect against projected health risks. Adaptation measures can be categorized into legislative policies, decision support tools, technology development, surveillance and monitoring of health data, infrastructure development, and other. Table 6 lists some adaptation measures for heatwave, extreme weather events, vectorborne diseases, waterborne diseases, and air pollution. These measures are generic because the local context, including vulnerabilities and adaptive capacity, need to be considered in the design of programs and activities to be implemented in a particular region.

Table 6: Adaptation Measures to Reduce Climate Change-Related Health Risks

	Heatwaves	Extreme Weather Events	Vectorborne Diseases	Waterborne Diseases	Air Pollution
Legislative Policies	Alter building design and infrastructure codes to reduce urban heat islands	Improve land use planning	Develop and maintain effective vector surveillance and control programs that incorporate climate change concerns	Ensure watershed protection and water quality laws are resilient to climate change	Develop and enforce regulations to reduce emissions of air pollutants from traffic, industry, and other sources Incentive programs to increase energy efficiency
Decision Support Tools	Enhance early warning systems	Enhance early warning systems and emergency response plans	Enhance early warning systems based on climate and environmental data for selected diseases	Develop early warning systems based on climate and environmental data for conditions that may increase selected diseases	Enhance alert systems for high air pollution days
Technology Development	Improve building design to reduce heat loads during summer months		Develop vaccines for West Nile virus and other vectorborne diseases Develop more rapid diagnostic tests	Develop more rapid diagnostic tests	
Surveillance and	Alter health data collection systems	Alter health data collection systems	Enhance vector surveillance and	Enhance surveillance and monitoring	Enhance health data collection

Monitoring	to monitor for increased morbidity and mortality during a heatwave	to monitor for disease outbreaks during and after an extreme event	control programs Monitor disease occurrence	programs for waterborne diseases	systems to monitor for health outcomes due to air pollution
Infrastructure Development	Improve urban design to reduce urban heat islands by planting trees, increasing green spaces, etc.	Design infrastructure to withstand projected extreme events	Consider possible impacts of infrastructure development, such as water storage tanks, on vectorborne diseases	Consider possible impacts of placement of sources of water- and foodborne pathogens (e.g., cattle near drinking water sources)	Improve public transit systems to reduce traffic emissions
Other	Conduct research on effective approaches to encourage appropriate behavior during a heatwave	Conduct research on effective approaches to encourage appropriate behavior during an extreme event			

An additional category of measures includes public education and outreach programs to provide information to the general public and specific vulnerable groups on climate risks to which they may be exposed and appropriate actions to take. Messages need to be specific to the region and group; for example, warnings to senior citizens of an impending heatwave should focus on keeping cool and drinking lots of water. Box 6 provides tips for dealing with extreme heatwaves developed by U.S. EPA with assistance from Federal, state, local, and academic partners (U.S. EPA, 2006).

Box 6: Quick Tips for Responding to Excessive Heat waves

For the Public

Do

- Use air conditioners or spend time in air-conditioned locations such as malls and libraries
- Use portable electric fans to exhaust hot air from rooms or draw in cooler air
- Take a cool bath or shower
- Minimize direct exposure to the sun
- Stay hydrated – regularly drink water or other nonalcoholic fluids
- Eat light, cool, easy-to-digest foods such as fruit or salads
- Wear loose fitting, light-colored clothes
- Check on older, sick, or frail people who may need help responding to the heat
- Know the symptoms of excessive heat exposure and the appropriate responses.

Don't

- Direct the flow of portable electric fans toward yourself when room temperature is hotter than 90°f
- Leave children and pets alone in cars for any amount of time
- Drink alcohol to try to stay cool
- Eat heavy, hot, or hard-to-digest foods
- Wear heavy, dark clothing.

Useful Community Interventions

For Public Officials

Send a clear public message

- Communicate that EHEs [extreme heat event] are dangerous and conditions can be life-threatening. In the event of conflicting environmental safety recommendations, emphasize that health protection should be the first priority.

Inform the public of anticipated EHE conditions

- When will EHE conditions be dangerous?
- How long will EHE conditions last?
- How hot will it FEEL at specific times during the day (e.g., 8 a.m., 12 p.m., 4 p.m., 8 p.m.)?

Assist those at greatest risk

- Assess locations with vulnerable populations, such as nursing homes and public housing
- Staff additional emergency medical personnel to address the anticipated increase in demand
- Shift/expand homeless intervention services to cover daytime hours

- Open cooling centers to offer relief for people without air conditioning and urge the public to use them.

Provide access to additional sources of information

- Provide toll-free numbers and Web site addresses for heat exposure symptoms and responses
- Open hotlines to report concerns about individuals who may be at risk
- Coordinate broadcasts of EHE response information in newspapers and on television and radio.

Source: U.S. EPA, 2006

3.6 Conclusions

The health impacts projected with climate change means there is a need to strengthen and improve programs and activities aimed at reducing the risks of climate-sensitive health determinants and outcomes. Proactive policies and measures should be identified that improve the context for adaptation, reduce exposures related to climate variability and change, prevent the onset of climate-sensitive health outcomes, and increase treatment options. Future community, state, and national assessments of the health impacts of climate variability and change should identify where gaps in adaptive capacity have not or are not being addressed.

Because of regional variability in the types of climate change attributable health stressors and associated responses, it is difficult to generally summarize adaptation at the national level. This difficulty is compounded by the fact that there is no central (or regional) agency responsible for adaptation. The elements needed, from weather forecasting to air and water quality regulations to vector control programs to disaster response, are spread across multiple agencies and organizations, with inconsistent collaboration. Public health adaptation will be facilitated by identifying and supporting a lead agency that can provide access to the information and tools needed for a particular adaptation measure, and that can support the adaptation process. Having a central agency that communities and states can call when they have questions about adaptation would be extremely beneficial and efficient. One model is the UK Climate Impacts Programme, funded by the UK government to provide downscaled climate projections and help the commercial and public sectors assess their vulnerability to climate change so that they can adapt effectively (http://www.ukcip.org.uk/). They bring together people from the private and public sectors with a shared interest, such as being in the same region or working in a particular sector, and support the adaptation process. The findings are used by the UK government's lead agency on climate change to inform policy.

Another model is the NOAA Regional Integrated Sciences and Assessments (RISA) program (http://www.climate.noaa.gov/cpo_pa/risa/). RISA centers have been funded in eight regions (five in Alaska and the West, the Pacific, the Southeast, and the Carolinas) that support research to address climate-sensitive issues of concern to regional decisionmakers and policy planners. These programs primarily focus on fisheries, water, wildfire, and agriculture, with limited focus on public health.

Overall, the U.S. has high capacity to cope with the projected health impacts of climate change. However, explicit consideration of climate change is needed in the many programs and research activities within federal, state, and local agencies that are relevant to adaptation to ensure that they have maximum effectiveness and timeliness in reducing future vulnerability.

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