Climate Change Impacts in the United States

CHAPTER 9
HUMAN HEALTH

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9 HUMAN HEALTH

Key Messages

1. **Climate change threatens human health and well-being in many ways, including impacts from increased extreme weather events, wildfire, decreased air quality, threats to mental health, and illnesses transmitted by food, water, and disease-carriers such as mosquitoes and ticks. Some of these health impacts are already underway in the United States.**
2. **Climate change will, absent other changes, amplify some of the existing health threats the nation now faces. Certain people and communities are especially vulnerable, including children, the elderly, the sick, the poor, and some communities of color.**
3. **Public health actions, especially preparedness and prevention, can do much to protect people from some of the impacts of climate change. Early action provides the largest health benefits. As threats increase, our ability to adapt to future changes may be limited.**
4. **Responding to climate change provides opportunities to improve human health and well-being across many sectors, including energy, agriculture, and transportation. Many of these strategies offer a variety of benefits, protecting people while combating climate change and providing other societal benefits.**

Climate change, together with other natural and human-made health stressors, influences human health and disease in numerous ways. Some existing health threats will intensify and new health threats will emerge. Not everyone is equally at risk. Important considerations include age, economic resources, and location. Preventive and adaptive actions, such as setting up extreme weather early warning systems and improving water infrastructure, can reduce the severity of these impacts, but there are limits to the effectiveness of such actions in the face of some projected climate change threats.

Climate change presents a global public health problem, with serious health impacts predicted to manifest in varying ways in different parts of the world. Public health in the U.S. can be affected by disruptions of physical, biological, and ecological systems, including disturbances originating in the U.S. and elsewhere. Health effects of these disruptions include increased respiratory and cardiovascular disease, injuries and premature deaths related to extreme weather events, changes in the prevalence and geographical distribution of food- and waterborne illnesses and other infectious diseases, and threats to mental health.

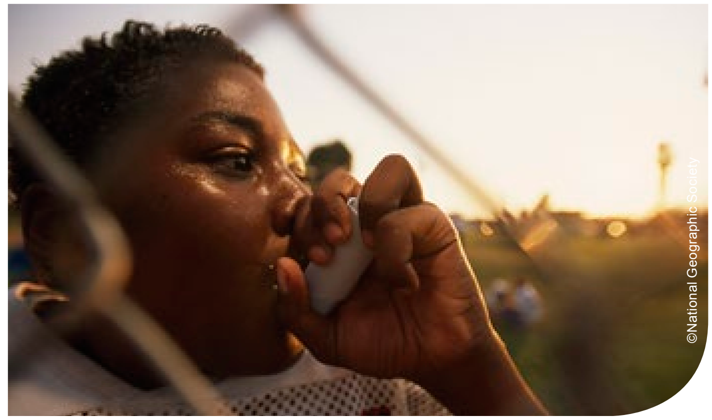
Key weather and climate drivers of health impacts include increasingly frequent, intense, and longer-lasting extreme heat, which worsens drought, wildfire, and air pollution risks; increasingly frequent extreme precipitation, intense storms, and changes in precipitation patterns that lead to drought and ecosystem changes (Ch. 2: Our Changing Climate); and rising sea levels that intensify coastal flooding and storm surge (Ch. 25: Coasts). Key drivers of vulnerability include the attributes of certain groups (age, socioeconomic status, race, current level of health – see Ch. 12: Indigenous Peoples for examples of health impacts on vulnerable populations) and of place (floodplains, coastal zones, and urban areas), as well as the resilience of critical public health infrastructure. Multi-stressor situations, such as impacts on vulnerable populations following natural disasters that also damage the social and physical infrastructure necessary for resilience and emergency response, are particularly important to consider when preparing for the impacts of climate change on human health.

Key Message 1: Wide-ranging Health Impacts

Climate change threatens human health and well-being in many ways, including impacts from increased extreme weather events, wildfire, decreased air quality, threats to mental health, and illnesses transmitted by food, water, and disease-carriers such as mosquitoes and ticks. Some of these health impacts are already underway in the United States.

Air Pollution

Climate change is projected to harm human health by increasing ground-level ozone and/or particulate matter air pollution in some locations. Ground-level ozone (a key component of smog) is associated with many health problems, such as diminished lung function, increased hospital admissions and emergency room visits for asthma, and increases in premature deaths.[1,2,3] Factors that affect ozone formation include heat, concentrations of precursor chemicals, and methane emissions, while particulate matter concentrations are affected by wildfire emissions and air stagnation episodes, among other factors.[4,5] By increasing these different factors, climate change is projected to lead to increased concentration of ozone and particulate matter in some regions.[6,7,8,9] Increases in global temperatures could cause associated increases in premature deaths related to worsened ozone and particle pollution. Estimates made assuming no change in regulatory controls or population characteristics have ranged from 1,000 to 4,300 additional premature deaths nationally per year by 2050 from combined ozone and particle health effects.[10,11] There is less



certainty in the responses of airborne particles to climate change than there is about the response of ozone. Health-related costs of the current effects of ozone air pollution exceeding national standards have been estimated at $6.5 billion (in 2008 U.S. dollars) nationwide, based on a U.S. assessment of health impacts from ozone levels during 2000 to 2002.[12,13]

Climate Change Projected to Worsen Asthma

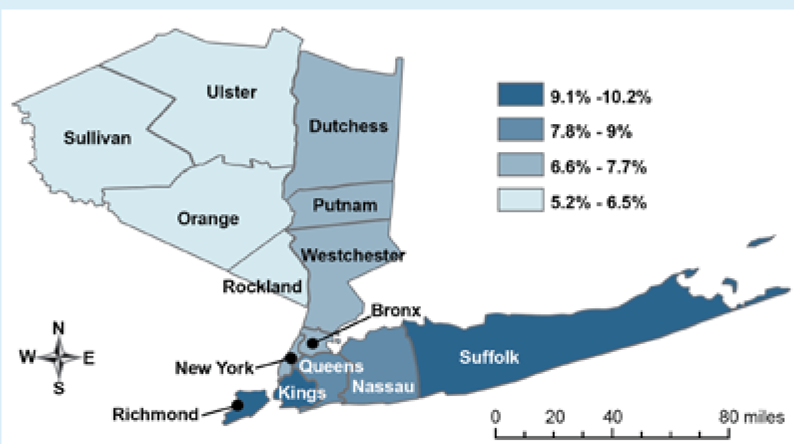


Figure 9.1. Projected increases in temperature, changes in wind patterns, and ecosystem changes will all affect future ground-level ozone concentrations. Climate projections using an increasing emissions scenario (A2) suggest that ozone concentrations in the New York metropolitan region will increase because of future climate change. This figure shows the estimated increase in ozone-related emergency room visits for children in New York in the 2020s (compared to the mid-1990s) resulting from climate change related increases in ozone concentrations. The results from this modeling exercise are shown as a percent change in visits specifically attributed to ozone exposure. For example, the 10.2% increase in Suffolk County represents five additional emergency room visits that could be attributed to increased ozone exposure over the baseline of 46 ozone-related visits from the mid-1990s. In 2010, an estimated 25.7 million Americans had asthma, which has become a problem in every state. (Figure source: Sheffield et al. 2011[14]).

Allergens

Climate change, resulting in more frost-free days and warmer seasonal air temperatures, can contribute to shifts in flowering time and pollen initiation from allergenic plant species, and increased CO_2 by itself can elevate production of plant-based allergens.[14,15,16,17,18,19] Higher pollen concentrations and longer pollen seasons can increase allergic sensitizations and asthma episodes,[20,21,22] and diminish productive work and school days.[19,22,23] Simultaneous exposure to toxic air pollutants can worsen allergic responses.[24,25,26] Extreme rainfall and rising temperatures can also foster indoor air quality problems, including the growth of indoor fungi and molds, with increases in respiratory and asthma-related conditions.[27] Asthma prevalence (the percentage of people who have ever been diagnosed with asthma and still have asthma) increased nationwide from 7.3% in 2001 to 8.4% in 2010. Asthma visits in primary care settings, emergency room visits, and hospitalizations were all stable from 2001 to 2009, and asthma death rates per 1,000 persons with asthma declined from 2001 to 2009.[28] To the extent that increased pollen exposures occur, patients and their physicians will face increased challenges in maintaining adequate asthma control.

Ragweed Pollen Season Lengthens

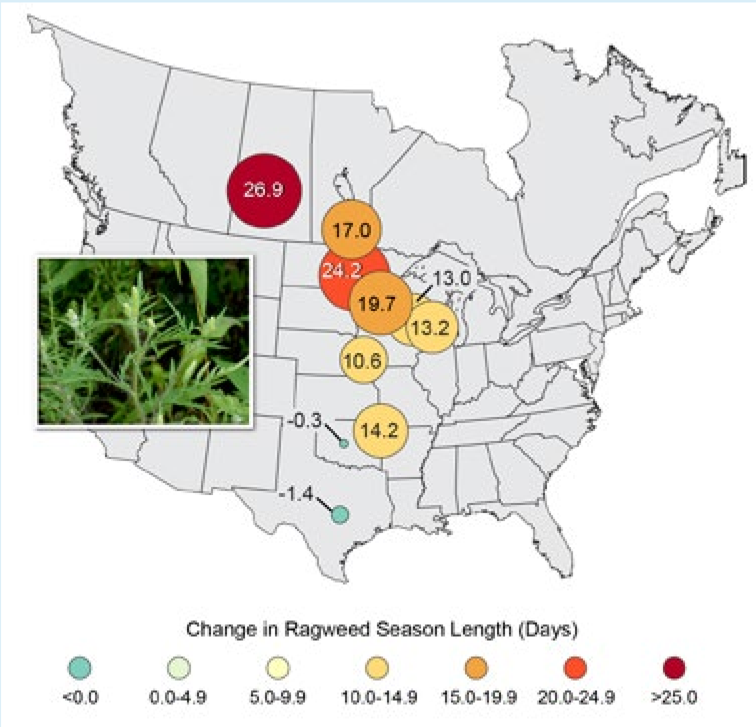


Figure 9.2. Ragweed pollen season length has increased in central North America between 1995 and 2011 by as much as 11 to 27 days in parts of the U.S. and Canada in response to rising temperatures. Increases in the length of this allergenic pollen season are correlated with increases in the number of days before the first frost. As shown in the figure, the largest increases have been observed in northern cities. (Data updated from Ziska et al. 2011[19]; Photo credit: Lewis Ziska, USDA).

Wildfires

Climate change is currently increasing the vulnerability of many forests to wildfire. Climate change is projected to increase the frequency of wildfire in certain regions of the United States (Ch. 7: Forests).[17,29] Long periods of record high temperatures are associated with droughts that contribute to dry conditions and drive wildfires in some areas.[30] Wildfire smoke contains particulate matter, carbon monoxide, nitrogen oxides, and various volatile organic compounds (which are ozone precursors)[31] and can significantly reduce air quality, both locally and in areas downwind of fires.[32,33] Smoke exposure increases respiratory and cardiovascular hospitalizations, emergency department visits, and medication dispensations for asthma, bronchitis, chest pain, chronic obstructive pulmonary disease (commonly known by its acronym, COPD), respiratory infections, and medical visits for lung illnesses.[32,34,35] It has been associated with hundreds of thousands of deaths annually, in an assessment of the global health risks from landscape fire smoke.[32,34,36,37] Future climate change is projected to increase wildfire risks and associated emissions, with harmful impacts on health.[17,38,39,40]

Wildfire Smoke has Widespread Health Effects

Figure 9.3. Wildfires, which are projected to increase in some regions due to climate change, have health impacts that can extend hundreds of miles. Shown here, forest fires in Quebec, Canada, during July 2002 (red circles) resulted in up to a 30-fold increase in airborne fine particle concentrations in Baltimore, Maryland, a city nearly a thousand miles downwind. These fine particles, which are extremely harmful to human health, not only affect outdoor air quality, but also penetrate indoors, increasing the long-distance effects of fires on health.[41] An average of 6.4 million acres burned in U.S. wildfires each year between 2000 and 2010, with 9.5 and 9.1 million acres burned in 2006 and 2012, respectively.[42] Total global deaths from the effects of landscape fire smoke have been estimated at 260,000 to 600,000 annually between the years 1997 and 2006.[37] (Figure source: Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on the Terra satellite, Land Rapid Response Team, NASA/GSFC).

Temperature Extremes

Extreme heat events have long threatened public health in the United States.[43,44,45] Many cities, including St. Louis, Philadelphia, Chicago, and Cincinnati, have suffered dramatic increases in death rates during heat waves. Deaths result from heat stroke and related conditions,[44,45,46] but also from cardiovascular disease, respiratory disease, and cerebrovascular disease.[47,48] Heat waves are also associated with increased hospital admissions for cardiovascular, kidney, and respiratory disorders.[48,49,50] Extreme summer heat is increasing in the United States (Ch. 2: Our Changing Climate, Key Message 7),[51] and climate projections indicate that extreme heat events will be more frequent and intense in coming decades (Ch. 2: Our Changing Climate, Key Message 7).[2,52,53,54]

Some of the risks of heat-related sickness and death have diminished in recent decades, possibly due to better forecasting, heat-health early warning systems, and/or increased access to air conditioning for the U.S. population.[55] However, extreme heat events remain a cause of preventable death nationwide. Urban heat islands, combined with an aging population and increased urbanization, are projected to increase the vulnerability of urban populations to heat-related health impacts in the future (Ch. 11: Urban).[56,57,58]

Milder winters resulting from a warming climate can reduce illness, injuries, and deaths associated with cold and snow. Vulnerability to winter weather depends on many non-climate factors, including housing, age, and baseline health.[59] While deaths and injuries related to extreme cold events are projected to decline due to climate change, these reductions are not expected to compensate for the increase in heat-related deaths.[60,61]

Projected Temperature Change of Hottest Days

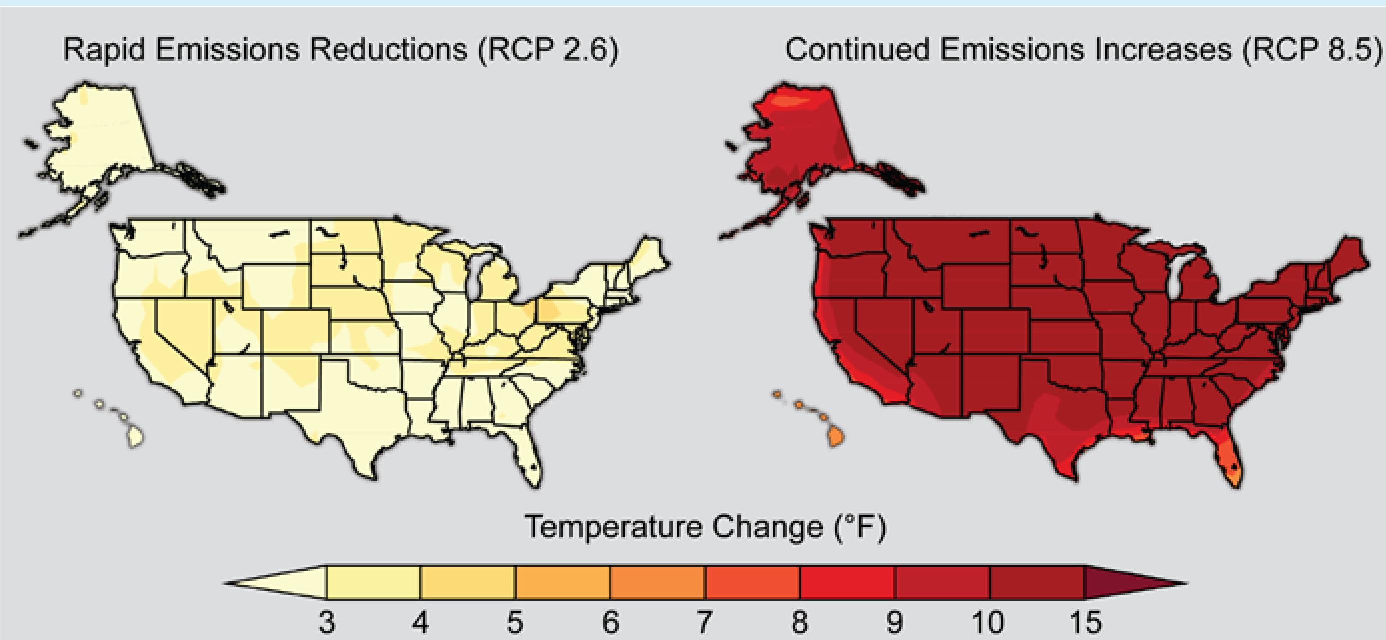


Figure 9.4. The maps show projected increases in the average temperature on the hottest days by late this century (2081-2100) relative to 1986-2005 under a scenario that assumes a rapid reduction in heat-trapping gases (RCP 2.6) and a scenario that assumes continued increases in these gases (RCP 8.5). The hottest days are those so hot they occur only once in 20 years. Across most of the continental United States, those days will be about 10ºF to 15ºF hotter in the future under the higher emissions scenario. (Figure source: NOAA NCDC / CICS-NC).

Precipitation Extremes: Heavy Rainfall, Flooding, and Droughts

The frequency of heavy precipitation events has already increased for the nation as a whole, and is projected to increase in all U.S. regions (Ch. 2: Our Changing Climate).[54,62] Increases in both extreme precipitation and total precipitation have contributed to increases in severe flooding events in certain regions (see Ch. 2: Our Changing Climate, Figure 2.21). Floods are the second deadliest of all weather-related hazards in the United States, accounting for approximately 98 deaths per year,[63] most due to drowning.[64] Flash floods (see Ch. 3: Water, "Flood Factors and Flood Types") and flooding associated with tropical storms result in the highest number of deaths.[63]

In addition to the immediate health hazards associated with extreme precipitation events when flooding occurs, other hazards can often appear once a storm event has passed. Elevated waterborne disease outbreaks have been reported in the weeks following heavy rainfall,[65] although other variables may affect these associations.[66] Water intrusion into buildings can result in mold contamination that manifests later, leading to indoor air quality problems. Buildings damaged during hurricanes are especially susceptible to water intrusion. Populations living in damp indoor environments experience increased prevalence of asthma and other upper respiratory tract symptoms, such as coughing and wheezing[67] as well as lower respiratory tract infections such as pneumonia, Respiratory Syncytial Virus (RSV), and RSV pneumonia (see Figure 9.7).[68]

At the opposite end of precipitation extremes, drought also poses risks to public health and safety.[69] Drought conditions may increase the environmental exposure to a broad set of health hazards including wildfires, dust storms, extreme heat events, flash flooding, degraded water quality, and reduced water quantity. Dust storms associated with drought conditions contribute to degraded air quality due to particulates and have been associated with increased incidence of Coccidioidomycosis (Valley fever), a fungal pathogen, in Arizona and California.[70]

Disease Carried by Vectors

Climate is one of the factors that influence the distribution of diseases borne by vectors (such as fleas, ticks, and mosquitoes, which spread pathogens that cause illness).[71,72,73,74,75,76,77,78] The geographic and seasonal distribution of vector populations, and the diseases they can carry, depend not only on climate but also on land use, socioeconomic and cultural factors, pest control, access to health care, and human responses to disease risk, among other factors.[72,73,79,80,81] Daily, seasonal, or year-to-year climate variability can sometimes result in vector/pathogen adaptation and shifts or expansions in their geographic ranges.[73,74,81] Such shifts can alter disease incidence depending on vector-host interaction, host immunity, and pathogen evolution.[71] North Americans are currently at risk from numerous vector-borne diseases, including Lyme,[75,82,83,84] dengue fever,[85] West Nile virus,[86] Rocky Mountain spotted fever,[87] plague, and tularemia.[88] Vector-borne pathogens not currently found in the United States, such as chikungunya, Chagas disease, and Rift Valley fever viruses, are also threats. Climate change effects on the geographical distribution and incidence of vector-borne diseases in other countries where these diseases are already found can also affect North Americans, especially as a result of increasing trade with, and travel to, tropical and subtropical areas.[74,81] Whether climate change in the U.S. will increase the chances of domestically acquiring diseases such as dengue fever is uncertain, due to vector-control efforts and lifestyle factors, such as time spent indoors, that reduce human-insect contact.

Infectious disease transmission is sensitive to local, small-scale differences in weather, human modification of the landscape, the diversity of animal hosts,[83] and human behavior that affects vector-human contact, among other factors. There is a need for finer-scale, long-term studies to help quantify the relationships among weather variables, vector range, and vector-borne pathogen occurrence, the consequences of shifting distributions of vectors and pathogens, and the impacts on human behavior. Enhanced vector surveillance and human disease tracking are needed to address these concerns.

The *Culex tarsalis* mosquito is a vector that transmits West Nile Virus.

Transmission cycle of Lyme disease

The development and survival of blacklegged ticks, their animal hosts, and the Lyme disease bacterium, *Borrelia burgdorferi*, are strongly influenced by climatic factors, especially temperature, precipitation, and humidity. Potential impacts of climate change on the transmission of Lyme disease include: 1) changes in the geographic distribution of the disease due to the increase in favorable habitat for ticks to survive off their hosts;[89] 2) a lengthened transmission season due to earlier onset of higher temperatures in the spring and later onset of cold and frost; 3) higher tick densities leading to greater risk in areas where the disease is currently observed, due to milder winters and potentially larger rodent host populations; and 4) changes in human behaviors, including increased time outdoors, which may increase the risk of exposure to infected ticks.

Projected Changes in Tick Habitat

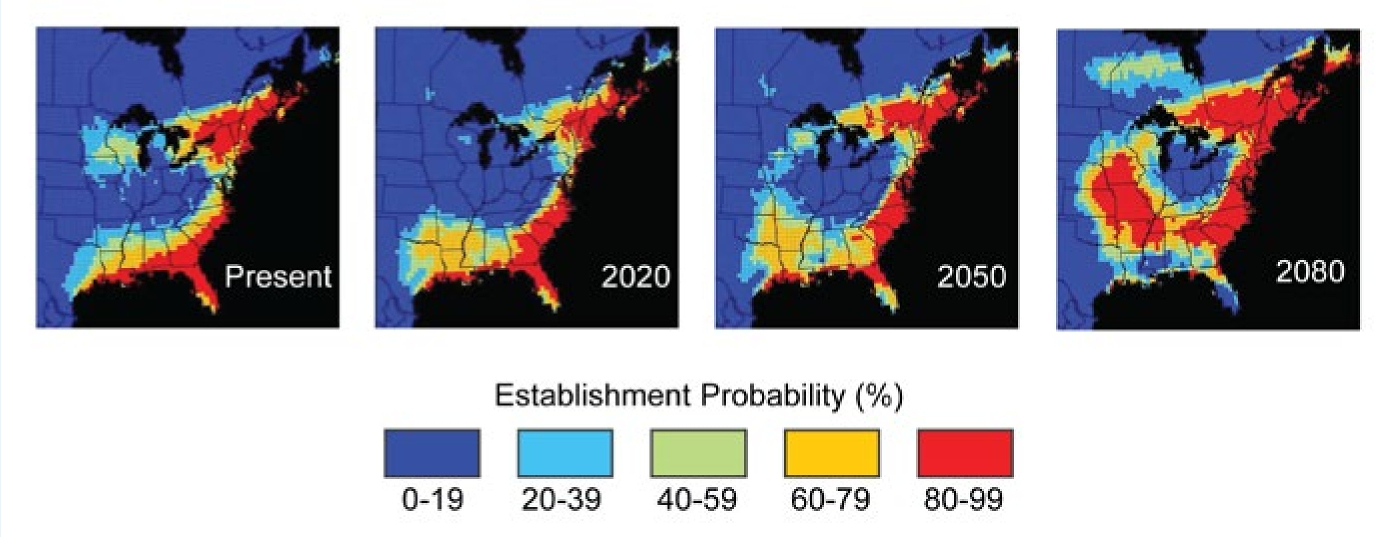


Figure 9.5. The maps show the current and projected probability of establishment of tick populations (*Ixodes scapularis*) that transmit Lyme disease. Projections are shown for 2020, 2050, and 2080. The projected expansion of tick habitat includes much of the eastern half of the country by 2080. For some areas around the Gulf Coast, the probability of tick population establishment is projected to decrease by 2080. (Figure source: adapted from Brownstein et al. 2005[90]).

Food- and Waterborne Diarrheal Disease

Diarrheal disease is a major public health issue in developing countries and, while not generally increasing in the United States, remains a persistent concern nonetheless. Exposure to a variety of pathogens in water and food causes diarrheal disease. Air and water temperatures, precipitation patterns, extreme rainfall events, and seasonal variations are all known to affect disease transmission.[65,91,92] In the United States, children and the elderly are most vulnerable to serious outcomes, and those exposed to inadequately or untreated groundwater will be among those most affected.

In general, diarrheal diseases including Salmonellosis and Campylobacteriosis are more common when temperatures are higher,[93,94] though patterns differ by place and pathogen. Diarrheal diseases have also been found to occur more frequently in conjunction with both unusually high and low precipitation.[95] Sporadic increases in streamflow rates, often preceded by rapid snowmelt[96] and changes in water treatment,[97] have also been shown to precede outbreaks. Risks of waterborne illness and beach closures resulting from changes in the magnitude of recent precipitation (within the past 24 hours) and in lake temperature are expected to increase in the Great Lakes region due to projected climate change.[98,99]

Projected Change in Heavy Precipitation Events

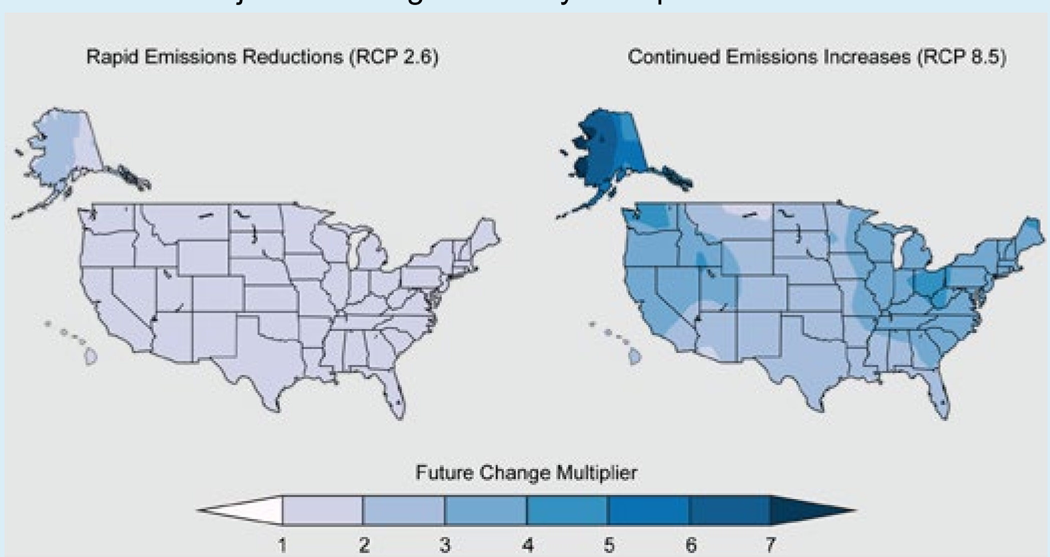


Figure 9.6. Maps show the increase in frequency of extreme daily precipitation events (a daily amount that now occurs just once in 20 years) by the later part of this century (2081-2100) compared to the latter part of the last century (1981-2000). Such extreme events are projected to occur more frequently everywhere in the United States. Under a rapid emissions reduction scenario (RCP 2.6), these events would occur nearly twice as often. For a scenario assuming continued increases in emissions (RCP 8.5), these events would occur up to five times as often. (Figure source: NOAA NCDC / CICS-NC).

Heavy Downpours are Increasing Exposure to Disease

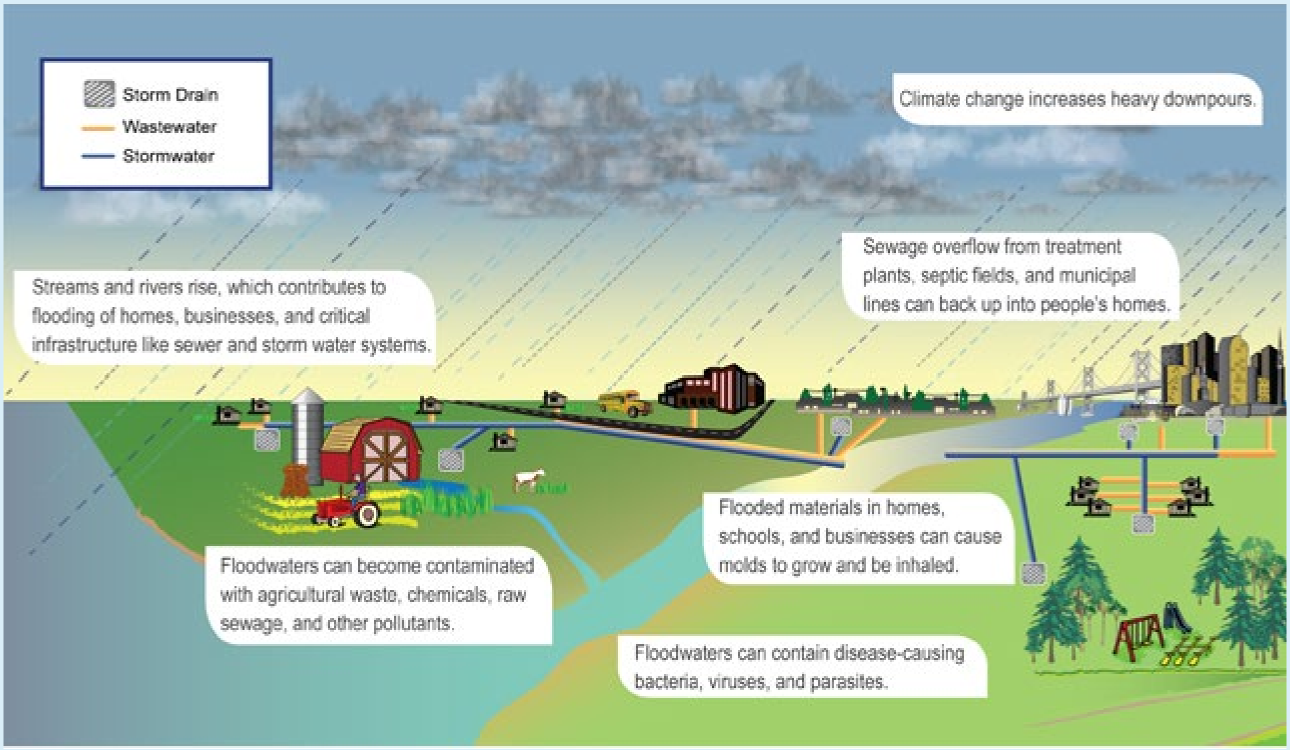


Figure 9.7. Heavy downpours, which are increasing in the United States, have contributed to increases in heavy flood events (Ch. 2: Our Changing Climate, Key Message 6). The figure above illustrates how people can become exposed to waterborne diseases. Human exposures to waterborne diseases can occur via drinking water, as well as recreational waters.[100,101,102,103] (Figure source: NOAA NCDC / CICS-NC).

Harmful Bloom of Algae

Figure 9.8. Remote sensing color image of harmful algal bloom in Lake Erie on October 9, 2011. The bright green areas have high concentrations of algae, which can be harmful to human health. The frequency and range of harmful blooms of algae are increasing.[102,103] Because algal blooms are closely related to climate factors, projected changes in climate could affect algal blooms and lead to increases in water- and food-borne exposures and subsequent cases of illness.[103] Other factors related to increases in harmful algal blooms include shifts in ocean conditions such as excess nutrient inputs.[101,102,103] (Figure source: NASA Earth Observatory[104]).

Food Security

Globally, climate change is expected to threaten food production and certain aspects of food quality, as well as food prices and distribution systems. Many crop yields are predicted to decline due to the combined effects of changes in rainfall, severe weather events, and increasing competition from weeds and pests on crop plants (Ch. 6: Agriculture, Key Message 6).[105,106] Livestock and fish production is also projected to decline.[107] Prices are expected to rise in response to declining food production and associated trends such as increasingly expensive petroleum (used for agricultural inputs such as pesticides and fertilizers).[108]

While the U.S. will be less affected than some other countries,[109,110] the nation will not be immune. Health can be affected in several ways. First, Americans with particular dietary patterns, such as Alaska Natives, will confront shortages of key foods (Ch. 12: Indigenous Peoples, Key Message 1).[111] Second, food insecurity increases with rising food prices.[112] In such situations, people cope by turning to nutrient-poor but calorie-rich foods, and/or they endure hunger, with consequences ranging from micronutrient malnutrition to obesity.[113] Third, the nutritional value of some foods is projected to decline. Elevated atmospheric CO_2 is associated with decreased plant nitrogen concentration, and therefore decreased protein, in many crops, such as barley, sorghum, and soy.[114] The nutrient content of crops is also projected to decline if soil nitrogen levels are suboptimal, with reduced levels of nutrients such as calcium, iron, zinc, vitamins, and sugars, although this effect is alleviated if sufficient nitrogen is supplied.[115] Fourth, farmers are expected to need to use more herbicides and pesticides because of increased growth of pests[116] and weeds[117] as well as decreased effectiveness[118] and duration[119] of some of these chemicals (Ch. 6: Agriculture). Farmers, farmworkers, and consumers will thus sustain increased exposure to these substances and their residues, which can be toxic. These climate change impacts on the nutritional value of food exist within a larger context in which other factors, such as agricultural practices, food distribution systems, and consumer food choices, also play key roles. Adaptation activities can reduce the health-related impacts of some of the anticipated food security challenges (Ch. 6: Agriculture).

Mental Health and Stress-related Disorders

Mental illness is one of the major causes of suffering in the United States, and extreme weather events can affect mental health in several ways.[120,121,122,123] First, following disasters, mental health problems increase, both among people with no history of mental illness, and those at risk – a phenomenon known as "common reactions to abnormal events." These reactions may be short-lived or, in some cases, long-lasting.[124] For example, research demonstrated high levels of anxiety and post-traumatic stress disorder among people affected by Hurricane Katrina,[125] and similar observations have followed floods[126] and heat waves.[127] Some evidence suggests wildfires have similar effects.[128] All of these events are increasingly fueled by climate change (see Ch. 2: Our Changing Climate). Other health consequences of intensely stressful exposures are also a concern, such as adverse birth outcomes including pre-term birth, low birth weight, and maternal complications.[129]

Second, some patients with mental illness are especially susceptible to heat.[130] Suicide rates vary with weather,[131] rising with high temperatures,[132] suggesting potential climate change impacts on depression and other mental illnesses. Dementia is a risk factor for hospitalization and death during heat waves.[127,133] Patients with severe mental illness such as schizophrenia are at risk during hot weather because their medications may interfere with temperature regulation or even directly cause hyperthermia.[134] Additional potential mental health impacts, less well understood, include the possible distress associated with environmental degradation[135] and displacement,[136] and the anxiety and despair that knowledge of climate change might elicit in some people (Ch. 12: Indigenous Peoples, Key Message 5).[122]

Key Message 2: Most Vulnerable at Most Risk

Climate change will, absent other changes, amplify some of the existing health threats the nation now faces. Certain people and communities are especially vulnerable, including children, the elderly, the sick, the poor, and some communities of color.

Climate change will increase the risk of climate-related illness and death for a number of vulnerable groups in the United States, as when Hurricane Katrina devastated New Orleans in 2005. Children, primarily because of physiological and developmental factors, will disproportionately suffer from the effects of heat waves,[47] air pollution, infectious illness, and trauma resulting from extreme weather events.[14,16,18,22,138,139,140,141]

The country's older population also could be harmed more as the climate changes. Older people are at much higher risk of dying during extreme heat events.[45,47,139,142] Pre-existing health conditions also make older adults susceptible to cardiac and respiratory impacts of air pollution[26] and to more severe consequences from infectious diseases;[143] limited mobility among older adults can also increase flood-related health risks.[144] Limited resources and an already high burden of chronic health conditions, including heart disease, obesity, and diabetes, will place the poor at higher risk of health impacts from climate change than higher income groups.[26,47] Potential increases in food cost and limited availability of some foods will exacerbate current dietary inequalities and have significant health ramifications for the poorer segments of our population (Ch. 12: Indigenous Peoples, Key Message 1).[110,145]

Climate change will disproportionately affect low-income communities and some communities of color (Ch. 12: Indigenous Peoples, Key Message 2),[139,149,151,152,153,154,155,156,157] raising environmental justice concerns. Existing health disparities[153,158,159] and other inequities[160,161] increase vulnerability. Climate change related issues that have an equity component include heat waves, air quality, and extreme weather and climate events. For example, Hurricane Katrina demonstrated how vulnerable certain groups of people were to extreme weather events, because many low-income and of-color New Orleans residents were killed, injured, or had difficulty evacuating and recovering from the storm.[154,155,156,161,162,163,164]

Elements of Vulnerability to Climate Change

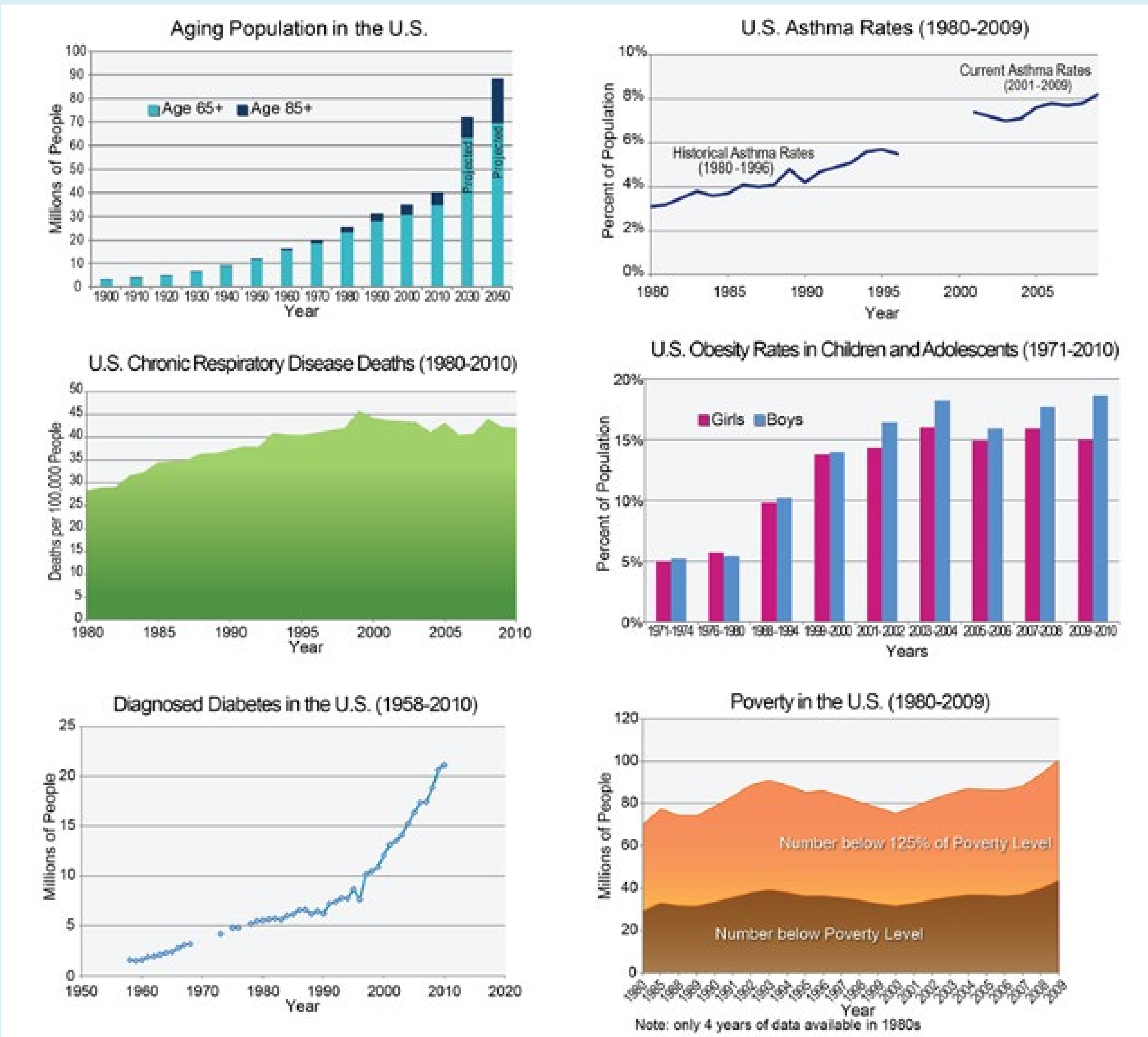


Figure 9.9. A variety of factors can increase the vulnerability of a specific demographic group to health effects due to climate change. For example, older adults are more vulnerable to heat stress because their bodies are less able to regulate their temperature. Overall population growth is projected to continue to at least 2050, with older adults comprising an increasing proportion of the population. Similarly, there are an increasing number of people who are obese and have diabetes, heart disease, or asthma, which makes them more vulnerable to a range of climate-related health impacts. Their numbers are also rising. The poor are less able to afford the kinds of measures that can protect them from and treat them for various health impacts. (Data from CDC; Health E-Stat; U.S. Census Bureau 2010, 2012; and Akinbami et al. 2011[137]).

Societal system failures during extreme events

We have already seen multiple system failures during an extreme weather event in the United States, as when Hurricane Katrina struck New Orleans.[146] Infrastructure and evacuation failures and collapse of critical response services during a storm is one example of multiple system failures. Another example is a loss of electrical power during a heat wave or wildfires, which can reduce food and water safety.[147] Air conditioning has helped reduce illness and death due to extreme heat,[148] but if power is lost, everyone is vulnerable. By their nature, such events can exceed our capacity to respond.[79] In succession, these events severely deplete our resources needed to respond, from the individual to the national scale, but disproportionately affect the most vulnerable populations.[149]

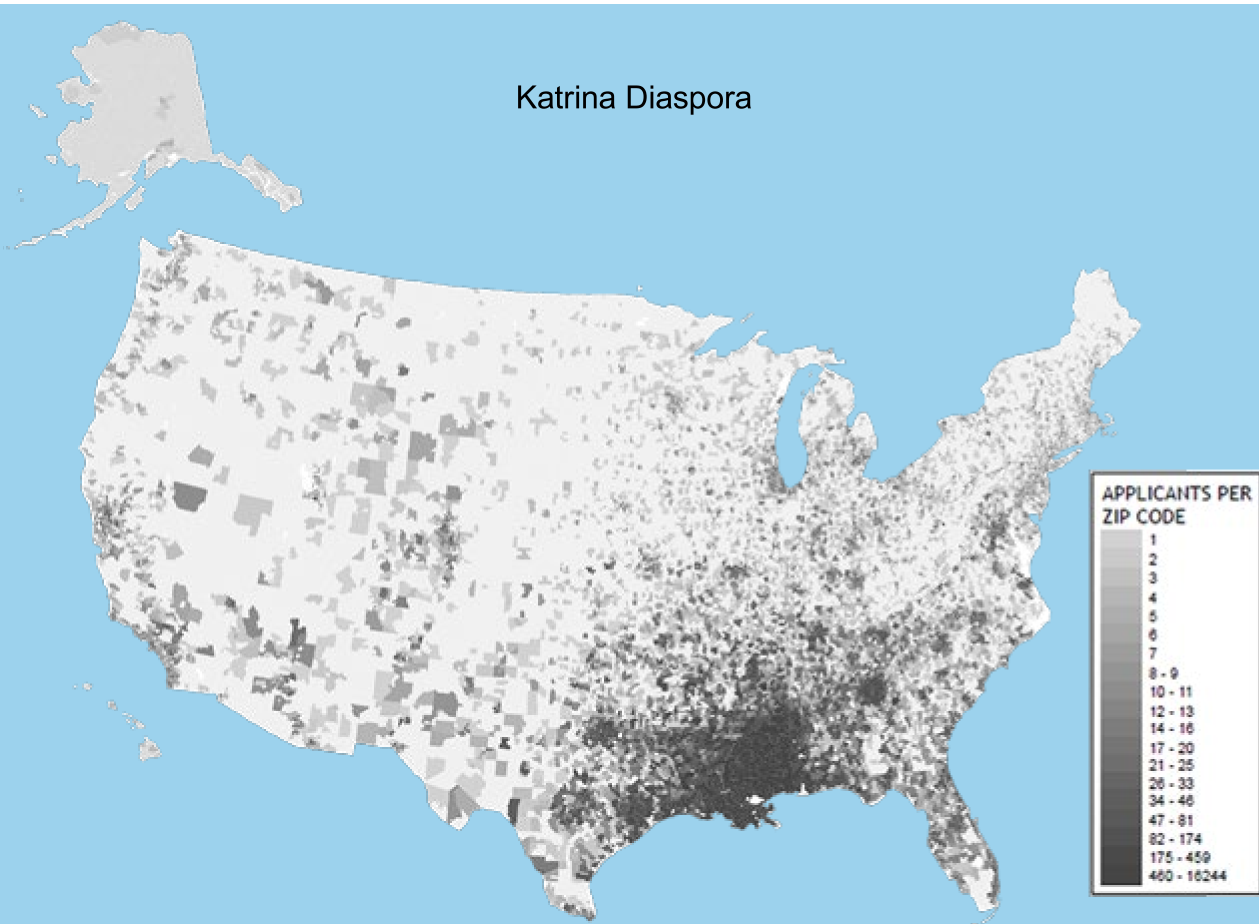


Figure 9.10. This map illustrates the national scope of the dispersion of displaced people from Hurricane Katrina. It shows the location by zip code of the 800,000 displaced Louisiana residents who requested federal emergency assistance. The evacuees ended up dispersed across the entire nation, illustrating the wide-ranging impacts that can flow from extreme weather events, such as those that are projected to increase in frequency and/or intensity as climate continues to change (Ch. 2: Our Changing Climate, Key Message 8). (Figure source: Kent 2006[150]).

Multiple climate stressors and health

Climate change impacts add to the *cumulative* stresses currently faced by vulnerable populations including children, the elderly, the poor, some communities of color, and people with chronic illnesses. These populations, and others living in certain places such as cities, floodplains, and coastlines, are more vulnerable not only to extreme events but also to ongoing, persistent climate-related threats. These threats include poor air quality, heat, drought, flooding, and mental health stress. Over time, the accumulation of these stresses will be increasingly harmful to these populations.

Key Message 3: Prevention Provides Protection

Public health actions, especially preparedness and prevention, can do much to protect people from some of the impacts of climate change. Early action provides the largest health benefits. As threats increase, our ability to adapt to future changes may be limited.

Prevention is a central tenet of public health. Many conditions that are difficult and costly to treat when a patient gets to the doctor could be prevented before they occur at a fraction of the cost. Similarly, many of the larger health impacts associated with climate change can be prevented through early action at significantly lower cost than dealing with them after they occur.[153,165] Early preventive interventions, such as early warnings for extreme weather, can be particularly cost-effective.[166,167,168] As with many illnesses,[169] once impacts are apparent, even the best adaptive efforts can be overwhelmed, and damage control becomes the priority.[62]

Activities that reduce carbon pollution often also provide co-benefits in the form of preventive health measures. For example, reliance on cleaner energy sources for electricity production[174] and more efficient and active transport, like biking or walking,[175] can have immediate public health benefits, through improved air quality and lowered rates of obesity, diabetes, and heart disease.[176] Reducing carbon pollution also reduces long-term adverse climate-health impacts, thus producing cost savings in the near and longer term.[176] Preventing exposures to other climate-sensitive impacts already apparent can similarly result in cost savings. For instance, heat wave early warning systems protect vulnerable groups very effectively and are much less expensive than treating and coping with heat illnesses. Systems that monitor for early outbreaks of disease are also typically much less expensive than treating communities once outbreaks take hold.[12,49,177]

Large-scale environmental change favors disease emergence

Climate change is causing large-scale changes in the environment, increasing the likelihood of the emergence or reemergence of unfamiliar disease threats.[170] Factors include shifting ranges of disease-carrying pests, lack of immunity and preparedness, inadequate disease monitoring, and increasing global travel. Diseases including Lyme disease and dengue fever pose increasing health threats to the U.S. population; the number of U.S. patients hospitalized with dengue fever more than tripled from 2000 to 2007.[171] Although most cases of dengue fever during that time period were acquired outside the contiguous United States, the introduction of infected people into areas where the dengue virus vector is established increases the risk of locally acquired cases. The public health system is not fully prepared to monitor or respond to these growing disease risks. The introduction of new diseases into non-immune populations has been and continues to be a major challenge in public health. There are concerns that climate change may provide opportunities for pathogens to expand or shift their geographic ranges.[172,173]

Effective communication is a fundamental part of prevention. The public must understand risk in order to endorse proactive risk management. The public is familiar with the health risks of smoking, but not so for climate change. When asked about climate change impacts, Americans do not mention health impacts,[178] and when asked about health impacts specifically, most believe it will affect people in a different time or place.[179] But diverse groups of Americans find information on health impacts to be helpful once received, particularly information about the health benefits of mitigation (reducing carbon emissions) and adaptation.[180]

Determining which types of prevention to invest in (such as monitoring, early warning systems, and land-use changes that reduce the impact of heat and floods) depends on several factors, including health problems common to that particular area, vulnerable populations, the preventive health systems already in place, and the expected impacts of climate change.[181] Local capacity to adapt is very important; unfortunately the most vulnerable populations also frequently have limited resources for managing climate-health risks.

Overall, the capacity of the American public health and health care delivery systems faces many challenges.[182] The cost of dealing with current health problems is diverting resources from preventing them in the first place. This makes the U.S. population more vulnerable.[183,184] Without careful consideration of how to prevent future impacts, similar patterns could emerge regarding the health impacts from climate change. However, efforts to quantify and map vulnerability factors at the community level are underway.[151,164,185]

There are public health programs in some locations that address climate-sensitive health issues, and integrating such programs into the mainstream public health toolkit as adaptation needs increase would improve public health resilience to climate change.[79,186,187] Given that these programs have demonstrated efficacy against current threats that are expected to worsen with climate change, it is prudent to invest in creating the strongest climate-health preparedness programs possible.[153] One survey highlighted opportunities to address climate change preparedness activities and climate-health research[181] before needs become more widespread. *America's Climate Choices: Adapting to the Impacts of Climate Choices* (Table 3.5) provides examples of health adaptation options.[187]

Key Message 4: Responses Have Multiple Benefits

Responding to climate change provides opportunities to improve human health and well-being across many sectors, including energy, agriculture, and transportation. Many of these strategies offer a variety of benefits, protecting people while combating climate change and providing other societal benefits.

Policies and other strategies intended to reduce carbon pollution and mitigate climate change can often have independent influences on human health. For example, reducing CO_2 emissions through renewable electrical power generation can reduce air pollutants like particles and sulfur dioxide. Efforts to improve the resiliency of communities and human infrastructure to climate change impacts can also improve human health. There is a growing recognition that the magnitude of health "co-benefits," like reducing both pollution and cardiovascular disease, could be significant, both from a public health and an economic standpoint.[176,188,189] Some climate change resilience efforts will benefit health, but potential co-harms should be considered when implementing these strategies. For example, although there are numerous benefits to urban greening, such as reducing the urban heat island effect while simultaneously promoting an active healthy lifestyle,[159,190,191] the urban planting of certain allergenic pollen producing species[22] could increase human pollen exposure and allergic illness. Increased pollen exposure has been linked to increased emergency department visits related to asthma and wheezing[192] in addition to respiratory allergic illnesses such as allergic rhinitis or hay fever.[193] The selective use of low to moderate pollen-producing species can decrease pollen exposure.[194]

Much of the focus of health co-benefits has been on reducing health-harming air pollution.[6,174,175,195,196] One study projects that replacing 50% of short motor vehicle trips with bicycle use and the other 50% with other forms of transportation like walking or public transit would avoid nearly 1,300 deaths in 11 midwestern metropolitan areas and create up to $8 billion in health benefits annually for the upper Midwest region.[188] Such multiple-benefit actions can reduce heat-trapping gas emissions that lead to climate change, improve air quality by reducing vehicle pollutant emissions, and improve fitness and health through increased physical activity.[99,197,198,199,200]

Innovative urban design could create increased access to active transport.[99] The compact geographical area found in cities presents opportunities to reduce energy use and emissions of heat-trapping gases and other air pollutants through active transit, improved building construction, provision of services, and infrastructure creation, such as bike paths and sidewalks.[197,201] Urban planning strategies designed to reduce the urban heat island effect, such as green/cool roofs, increased green space, parkland and urban canopy, could reduce indoor temperatures, improve indoor air quality, and could produce additional societal co-benefits by promoting social interaction and prioritizing vulnerable urban populations.[191,197]

Patterns of change related to improving health can also have co-benefits in terms of reducing carbon pollution and mitigating climate change. Current U.S. dietary guidelines and many health professionals have recommended diets higher in fruits and vegetables and lower in red meat as a means of helping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to reduce the risk of cardiovascular disease and some cancers.[199,202,203] These changes in food consumption, and related changes to food production, could have co-benefits in terms of reducing greenhouse gas emissions. While the greenhouse gas footprint of the production of other foods, compared to sources such as livestock, is highly dependent on a number of factors, production of livestock currently accounts for about 30% of the U.S. total emissions of methane.[199,203,204] This amount of methane can be reduced somewhat by recovery methods such as the use of biogas digesters, but future changes in dietary practices, including those motivated by considerations other than climate change mitigation, could also have an effect on the amount of methane emitted to the atmosphere.[205]

In addition to producing health co-benefits,[206] climate change prevention and preparedness measures could also yield positive equity impacts. For example, several studies have found that communities of color and poor communities experience disproportionately high exposures to air pollution.[207,208] Climate change mitigation policies that improve local air quality thus have the potential to strongly benefit health in these communities.

An area where adaptation policy could produce more equitable health outcomes is with respect to extreme weather events. As discussed earlier, Hurricane Katrina demonstrated that communities of color, poor communities, and certain other vulnerable populations (like new immigrant communities) are at a higher risk to the adverse effects of extreme weather events.[152,155] These vulnerable populations could benefit from urban planning policies that ensure that new buildings, including homes, are constructed to resist extreme weather events.[197]

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Introduction to chapter; tourists walking close to misters keeping cool during heat wave in Las Vegas, Nevada, as shown in top banner: ©Julie Jacobson/AP/Corbis

SUPPLEMENTAL MATERIAL

TRACEABLE ACCOUNTS

Process for Developing Key Messages

The key messages were developed during technical discussions and expert deliberation at a two-day meeting of the eight chapter Lead Authors, plus Susan Hassol and Daniel Glick, held in Boulder, Colorado May 8-9, 2012; through multiple technical discussions via six teleconferences from January through June 2012, and an author team call to finalize the Traceable Account draft language on Oct 12, 2012; and through other various communications on points of detail and issues of expert judgment in the interim. The author team also engaged in targeted consultations during multiple exchanges with Contributing Authors, who provided additional expertise on subsets of the key message. These discussions were held after a review of the technical inputs and associated literature pertaining to human health, including a literature review,[209] workshop reports for the Northwest and Southeast United States, and additional technical inputs on a variety of topics.

Key message #1 Traceable Account

Climate change threatens human health and well-being in many ways, including impacts from increased extreme weather events, wildfire, decreased air quality, threats to mental health, and illnesses transmitted by food, water, and diseases-carriers such as mosquitoes and ticks. Some of these health impacts are already underway in the United States.

Description of evidence base

The key message and supporting text summarizes extensive evidence documented in several foundational technical inputs prepared for this chapter, including a literature review[209] and workshop reports for the Northwest and Southeast United States. Nearly 60 additional technical inputs related to human health were received and reviewed as part of the Federal Register Notice solicitation for public input.

Air Pollution:

The effects of decreased ozone air quality on human health have been well documented concerning projected increases in ozone,[6,7,9,11,39] even with uncertainties in projections owing to the complex formation chemistry of ozone and climate change, precursor chemical inventories, wildfire emission, stagnation episodes, methane emissions, regulatory controls, and population characteristics.[4] Ozone exposure leads to a number of health impacts.[1,2]

Allergens:

The effects of increased temperatures and atmospheric CO_2 concentration have been documented concerning shifts in flowering time and pollen initiation from allergenic plants, elevated production of plant-based allergens, and health effects of increased pollen concentrations and longer pollen seasons.[15,16,17,18,20,22,23,24,26,106] Additional studies have shown extreme rainfall and higher temperatures can lead to increased indoor air quality issues such as fungi and mold health concerns.[27]

Wildfire:

The effects of wildfire on human health have been well documented with increase in wildfire frequency[17,29,39,40] leading to decreased air quality[31,32,33] and negative health impacts.[32,34,36]

Temperature Extremes:

The effects of temperature extremes on human health have been well documented for increased heat waves,[51,53,54] which cause more deaths,[47,48] hospital admissions[50] and population vulnerability.[56,57]

Precipitation Extremes - Heavy Rainfall, Flooding, and Droughts:

The effects of weather extremes on human health have been well documented, particularly for increased heavy precipitation, which has contributed to increases in severe flooding events in certain regions. Floods are the second deadliest of all weather-related hazards in the United States.[63,64] Elevated waterborne disease outbreaks have been reported in the weeks following heavy rainfall,[65] although other variables may affect these associations.[66] Populations living in damp indoor environments experience increased prevalence of asthma and other upper respiratory tract symptoms.[67]

Disease Carried by Vectors:

Climate is one of the factors that influence the range of disease vectors;[73,74,76] a shift in the current range may increase interactions with people and affect human health.[71] North Americans are currently at risk from a number of vector-borne diseases.[75,82,83,85,86,87] There are some ambiguities on the relative role and contribution of climate change among the range of factors that affect disease transmission dynamics.[71,72,73,74,75,76] However, observational studies are already underway and confidence is high based on scientific literature that climate change has contributed to the expanded range of certain disease vectors, including *Ixodes* ticks which are vectors for Lyme disease in the United States.[78,84,89]

Food- and Waterborne Diarrheal Disease:
There has been extensive research concerning the effects of climate change on water- and food-borne disease transmission.[92,93,95,96,97] The current evidence base strongly supports waterborne diarrheal disease being both seasonal and sensitive to climate variability. There are also multiple studies associating extreme precipitation events with waterborne disease outbreaks.[65] This evidence of responsiveness of waterborne disease to weather and climate, combined with evidence strongly suggesting that temperatures will increase and extreme precipitation events will increase in frequency and severity (Ch. 2: Our Changing Climate), provides a strong argument for climate change impacts on waterborne disease by analogy. There are multiple studies associating extreme precipitation events with waterborne disease outbreaks and strong climatological evidence for increasing frequency and intensity of extreme precipitation events in the future. The scientific literature modeling the projected impacts of climate change on waterborne disease is somewhat limited, however. Combined, we therefore have overall medium confidence in the impact of climate change on waterborne and food-borne disease.

Harmful Algal Blooms:
Because algal blooms are closely related to climate factors, projected changes in climate could affect algal blooms and lead to increases in food- and waterborne exposures and subsequent cases of illness.[96,97,98,99,103] Harmful algal blooms have multiple exposure routes.[100]

Food Security:
Climate change is expected to have global impacts on both food production and certain aspects of food quality. The impact of temperature extremes, changes in precipitation and elevated atmospheric CO_2, and increasing competition from weeds and pests on crop plants are areas of active research (Ch. 6: Agriculture, Key Message 6).[105,106] The U.S. as a whole will be less affected than some other countries. However, the most vulnerable, including those dependent on subsistence lifestyles, especially Alaska Natives and low-income populations, will confront shortages of key foods.

Mental Health and Stress-Related Disorders:
The effects of extreme weather on mental health have been extensively studied.[120,122,123] Studies have shown the impacts of mental health problems after disasters,[124] with extreme events like Hurricane Katrina,[125] floods,[126] heat waves,[127] and wildfires[128] having led to mental health problems. Further work has shown that some people with mental illnesses are especially vulnerable to heat. Suicide rates vary with weather,[131,132] dementia is a risk factor for hospitalization and death during heat waves,[127,133] and medications for schizophrenia may interfere with temperature regulation or even directly cause hyperthermia.[134] Additional potential mental health impacts include distress associated with environmental degradation, displacement, and the knowledge of climate change.[122,123,136]

New information and remaining uncertainties
Important new evidence on heat-health effects[44,45] confirmed many of the findings from a prior literature review. Uncertainties in the magnitude of projections of future climate-related morbidity and mortality can result from differences in climate model projections of the frequency and intensity of extreme weather events such as heat waves and other climate parameters such as precipitation.

Efforts to improve the information base should address the coordinated monitoring of climate and improved surveillance of health effects.

Assessment of confidence based on evidence
Overall: **Very High** confidence. There is considerable consensus and a high quality of evidence in the published peer-reviewed literature that a wide range of health effects will be exacerbated by climate change in the United States. There is less agreement on the magnitude of these effects because of the exposures in question and the multi-factorial nature of climate-health vulnerability, with regional and local differences in underlying health susceptibilities and adaptive capacity. Other uncertainties include how much effort and resources will be put into improving the adap-

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

tive capacity of public health systems to prepare in advance for the health effects of climate change, prevent harm to individual and community health, and limit associated health burdens and societal costs.

Increased Ozone Exposure: **Very High** confidence.
Allergens: **High** confidence.
Wildfires: **Very High** confidence.
Thermal Extremes: **Very High** confidence.
Extreme Weather Events: **Very High** confidence.
Vector-borne Infectious Diseases: **High** or **Very High** confidence for shift in range of disease-carrying vectors. **Medium** confidence for whether human disease transmission will follow.
Food- and Waterborne disease: **Medium** confidence.
Harmful Algal Blooms: **Medium** confidence.
Food Security: **Medium** confidence for food quality; **High** confidence for food security.

Threats to Mental Health: **Very High** confidence for post-disaster impacts; **Medium** confidence for climate-induced stress.

Key message #2 Traceable Account

Climate change will, absent other changes, amplify some of the existing health threats the nation now faces. Certain people and communities are especially vulnerable, including children, the elderly, the sick, the poor, and some communities of color.

Description of evidence base

The key message and supporting text summarizes extensive evidence documented in several foundational technical inputs prepared for this chapter, including a literature review[209] and workshop reports for the Northwest and Southeast regions.[210] Nearly 60 additional technical inputs related to human health were received and reviewed as part of the Federal Register Notice solicitation for public input.

Current epidemiological evidence on climate-sensitive health outcomes in the U.S. indicates that health impacts will differ substantially by location, pathway of exposure, underlying susceptibility, and adaptive capacity. These disparities in health impacts will largely result from differences in the distribution of individual attributes in a population that confers vulnerability (age, socioeconomic status, and race), attributes of place that reduce or amplify exposure (floodplain, coastal zone, and urban heat island), and the resilience of critical public health infrastructure.

Amplification of existing health threats: The effects of extreme heat and heat waves, projected worsening air pollution and asthma, extreme rainfall and flooding, and displacement and injuries associated with extreme weather events, fueled by climate change, are already substantial public health issues. Trends projected under a changing climate are projected to exacerbate these health effects in the future.[62]

Children: The effects of climate change increase vulnerability of children to extreme heat, and increased health damage (morbidity, mortality) resulting from heat waves has been well documented.[16,22,51,53,140] Extreme heat also causes more pediatric deaths,[47,48] and more emergency room visits and hospital admissions.[49,50] Adverse effects from increased heavy precipitation can lead to more pediatric deaths, waterborne diseases,[66] and illness.[141]

The elderly: Heat stress is especially damaging to the health of older people,[45,49,60,133,142,209] as are climate-sensitive increases in air pollution.

The sick: People and communities lacking the resources to adapt or to enhance mobility and escape health-sensitive situations are at relatively high risk.[164]

The poor: People and communities lacking the resources to adapt or to move and escape health-sensitive situations are at relatively high risk.[164]

Some communities of color: There are racial disparities in climate-sensitive exposures to extreme heat in urban areas, and in access to means of adaptation – for example air conditioning use.[149,151,157,211] There are also racial disparities in withstanding, and recovering from, extreme weather events.[155,162]

Climate change will disproportionately impact low-income communities and some communities of color, raising environmental justice concerns.[139,149,151,154,155,157,161,164] Existing health disparities[153,158,159] and other inequities[161] increase vulnerability. For example, Hurricane Katrina demonstrated how vulnerable these populations were to extreme weather events because many low-income and of-color New Orleans residents were killed, injured, or had difficulty evacuating and recovering from the storm.[155,162] Other climate change related issues that have an equity component include heat waves and air quality.[139,149,154,164]

New information and remaining uncertainties

Important new evidence[45] confirmed findings from a prior literature review.[139]

The potential for specific climate-vulnerable communities to experience highly harmful health effects is not entirely clear in specific regions and on specific time frames due to uncertainties in rates of adaptation and uncertainties about the outcome of public health interventions currently being implemented that aim to address underlying health disparities and determinants of health.[206] The public health community has not routinely conducted evaluations of the overall success of adaptation interventions or of particular elements of those interventions.

Assessment of confidence based on evidence

Given the evidence base and remaining uncertainties, confidence that climate change will amplify existing health threats: **Very High**.

Among those especially vulnerable are:

Children: **Very High**.

The elderly: **Very High**.

The sick: **Very High**.

The poor: **Very High**.

Some communities of color: **High**.

Key message #3 Traceable Account

Public health actions, especially preparedness and prevention, can do much to protect people from some of the impacts of climate change. Early action provides the largest health benefits. As threats increase, our ability to adapt to future changes may be limited.

Description of evidence base

The key message and supporting text summarizes extensive evidence documented in several foundational technical inputs prepared for this chapter, including a literature review[209] and workshop reports for the Northwest and Southeast United States. Nearly 60 additional technical inputs related to human health were received and reviewed as part of the Federal Register Notice solicitation for public input.

A number of studies have demonstrated that prevention activities that reduce carbon pollution, like using alternative energy sources[174] and using active transportation like biking or walking,[188] can lead to significant public health benefits, which can save costs in the near and long term.[176] Health impacts associated with climate change can be prevented through early action at significantly lower cost than dealing with them after they occur. For example, heat wave early warning systems are much less expensive than treating heat-related illnesses.[165] Existing adaptation programs have improved public health resilience.[9,153] One survey highlighted opportunities to address climate change preparedness activities and climate-health research[181] before needs become more widespread.

Considering U.S. public health in general, the cost-effectiveness of many prevention activities is well established.[183] Some preventive actions are cost-saving, while others are deemed cost-effective based on a pre-determined threshold. Early preventive interventions, such as early warnings for extreme weather, can be particularly cost-effective.[166] However, there is less information on the cost-effectiveness of specific prevention interventions relevant to climate sensitive health threats (for example, heat early warning systems). Overall, we have high confidence that public health actions can do much to protect people from some of the impacts of climate change, and that early action provides the largest health benefits.

The inverse relationship between the magnitude of an impact and a community's ability to adapt is well established and understood. Two extreme events, Hurricane Katrina and the European heat wave of 2003, illustrate this relationship well.[167] Extreme events interact with social vulnerability to produce extreme impacts, and the increasing frequency of extreme events associated with climate change is prompting concern for impacts that may overwhelm adaptive capacity.[62,173] This is equally true of the public health sector, specifically, leading to very high confidence that as threats increase, our ability to adapt to future changes may be limited.

New information and remaining uncertainties

A key issue (uncertainty) is the extent to which the nation, states, communities and individuals will be able to adapt to climate change because this depends on the levels of local exposure to climate-health threats, underlying susceptibilities, and the capacities to adapt that are available at each scale. Overall, the capacity of the American public health and health care delivery systems faces many challenges.[182] The cost of dealing with current health problems is diverting resources from preventing them in the first place. This makes the U.S. population more vulnerable.[56,183]

Steps for improving the information base on adaptation include undertaking a more comprehensive evaluation of existing climate-health preparedness programs and their effectiveness in various jurisdictions (cities, counties, states, nationally).

Assessment of confidence based on evidence

Overall, given the evidence base and remaining uncertainties: **High**.

High: Public health actions, especially preparedness and prevention, can do much to protect people from some of the impacts of climate change. Prevention provides the most protection; but we do not as yet have a lot of post-implementation information with which to evaluate preparedness plans.

High: Early action provides the largest health benefits. There is evidence that heat-health early warning systems have saved lives and money in U.S. cities like Philadelphia, PA.[165]

Very High: Our ability to adapt to future changes may be limited.

Key message #4 Traceable Account

Responding to climate change provides opportunities to improve human health and well-being across many sectors, including energy, agriculture, and transportation. Many of these strategies offer a variety of benefits, protecting people while combating climate change and providing other societal benefits.

Description of evidence base

The key message and supporting text summarizes extensive evidence documented in several foundational technical inputs prepared for this chapter, including a literature review[209] and workshop reports for the Northwest and Southeast U.S. regions.[210] Nearly 60 additional technical inputs related to human health were received and reviewed as part of the Federal Register Notice solicitation for public input.

A number of studies have explored the opportunities available to improve health and well-being as a result of adapting to climate change,[176] with many recent publications illustrating the benefit of reduced air pollution.[6,174,175,195] Additionally, some studies have looked at the co-benefits to climate change and health of applying innovative urban design practices which reduce energy consumption and pollution while increasing public health,[99,188,197,198] decrease vulnerability of communities to extreme events[152,197] and reduce the disparity between different societal groups.[206,207,212]

New information and remaining uncertainties

More studies are needed to fully evaluate both the intended and unintended health consequences of efforts to improve the resiliency of communities and human infrastructure to climate change impacts. There is a growing recognition that the magnitude of these health co-benefits or co-harms could be significant, both from a public health and an economic standpoint. [176,188,189]

Assessment of confidence based on evidence

Given the evidence base and remaining uncertainties, confidence is **Very High**.