9. Human Health

Convening Lead Authors

George Luber, Centers for Disease Control and Prevention

Kim Knowlton, Natural Resources Defense Council and Mailman School of Public Health, Columbia University

Lead Authors

John Balbus, National Institutes of Health

Howard Frumkin, University of Washington

Mary Hayden, University Corporation for Atmospheric Research

Jeremy Hess, Emory University

Michael McGeehin, Research Triangle Institute

Nicky Sheats, Thomas Edison State College

Contributing Authors

Lorraine Backer, Centers for Disease Control and Prevention

C. Ben Beard, Centers for Disease Control and Prevention

Kristie L. Ebi, Stanford University

Edward Maibach, George Mason University

Richard S. Ostfeld, Cary Institute of Ecosystem Studies

Christine Wiedinmyer, National Center for Atmospheric Research

Emily Zielinski-Gutiérrez, Centers for Disease Control and Prevention

Lewis Ziska, United States Department of Agriculture

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, diseases transmitted by insects, food and water, and threats to mental health. Some of these health impacts are already underway in the U.S.**
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, will influence human health and disease in many ways, regardless of whether prevention and adaptation efforts are undertaken. Evidence indicates that, absent these other changes (prevention/adaptation activities, infrastructure improvements) and with increasing population susceptibilities (aging, limited economic resources, etc.), some existing health threats will intensify and new health threats will emerge. Climate change is 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 elsewhere.

The health impacts of climate change will be highly variable. Key drivers of health impacts include: increasingly frequent and intense extreme heat, which also worsens drought and wildfire risks as well as air pollution; increasingly frequent extreme precipitation and associated flooding (see Ch. 2: Our Changing Climate); and rising sea levels that intensify coastal flooding and storm surge (see Ch. 25: Coastal Zone Development and Ecosystems). Key drivers of vulnerability include attributes of people (age, socioeconomic status, race) and of place (floodplain, coastal zone, urban areas), as well as the resilience of critical public health infrastructure.

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, diseases transmitted by insects, food and water, and threats to mental health. Some of these health impacts are already underway in the U.S.

Air Pollution

Climate change alone is projected to increase summertime ozone concentrations by 1 to 10 parts per billion this century (Bell et al. 2008; Chang et al. 2010; Ebi and McGregor 2008; EPA 2009; Post et al. 2012; Spickett et al. 2011; Tagaris et al. 2007). Ground-level ozone is associated with diminished lung function, increased hospital admissions and emergency room visits, and increases in premature mortality (Dennekamp and Carey 2010; Kampa and Castanas 2008; Kinney 2008). Current estimates suggest that 1,000 premature deaths per 1.8°F rise in temperature could occur each year related to worsened ozone and particle pollution (Ebi and McGregor 2008; Jacob and Winner 2009; Jacobson 2008; Kinney 2008; Liao et al. 2009; Spickett et al. 2011). Other studies project 4,300 additional premature deaths per year by 2050 (Russell et al. 2010; Tagaris et al. 2009). Health-related costs of climate change's current effects on ozone air pollution have been estimated at $6.5 billion nationwide (Knowlton et al. 2011; Östblom and Samakovlis 2007).

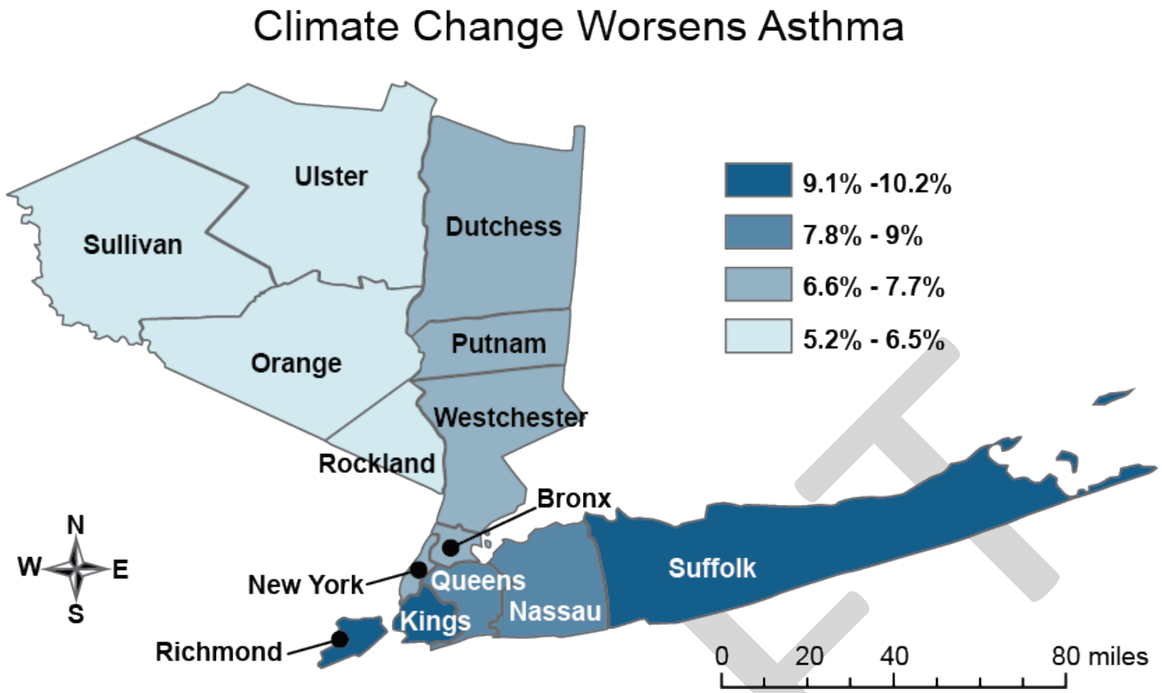

Figure 9.1: Climate Change Worsens Asthma

Caption: Percentage increases in emergency room visits for asthma related to ground-level ozone among children in the New York City region by the 2020s, resulting from the effects of climate change. Asthma accounts for one-quarter of all emergency room visits in the U.S. – 1.75 million each year. Costs for this chronic disease increased from an estimated $53 billion in 2002 to about $56 billion in 2007. In 2010, an estimated 25.7 million Americans had asthma, which has become a problem in every state. The condition is distinctly prevalent in California's Central Valley, where one out of every six children has asthma symptoms. (Sheffield et al. 2011b)

Allergens

Climate change can contribute to increased production of plant-based allergens (Emberlin et al. 2002; Pinkerton et al. 2012; Schmier and Ebi 2009; Shea et al. 2008; Sheffield and Landrigan 2011c; Sheffield et al. 2011b; Ziska et al. 2011). Higher pollen concentrations and longer pollen seasons increase allergic sensitizations and asthma episodes (Ariano et al. 2010; Breton et al. 2006; EPA 2008; Perry et al. 2011) and diminish productive work and school days (Sheffield et al. 2011a; Staudt et al. 2010; Ziska et al. 2011). Simultaneous exposure to air pollutants can worsen allergic responses (D'amato and Cecchi 2008; D'amato et al. 2010; Reid and Gamble 2009). Extreme rainfall and rising temperatures can also foster the growth of indoor fungi and molds, with increases in respiratory and asthma-related conditions (Fisk et al. 2007; IOM 2011; Mudarri and Fisk 2007; Wolf et al. 2010).

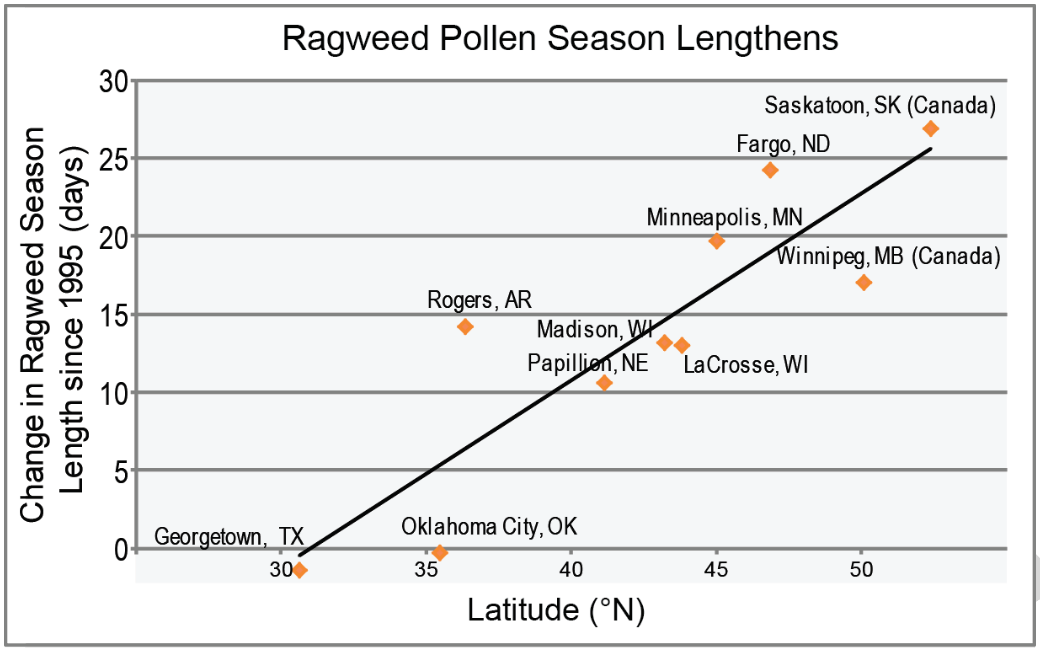

Figure 9.2: Ragweed Pollen Season Lengthens

Caption: Ragweed pollen season length has increased in central North America between 1995 and 2011, by as much as 13 to 27 days in parts of the U.S., 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 on the graph, the largest increases have been observed in northern cities. In 2012, a "perfect storm" of pollen-producing conditions across much of the U.S. – a warm winter leading to early pollen production among trees and plants, followed by hot, dry, low-humidity conditions through the spring and summer – contributed to wide circulation of aeroallergens and, "a horrendous year" for allergies, according to physicians. Additional data provided by L. Ziska. (Sources: EPA 2008; Fears 2012; Irfan 2012; Perry et al. 2011; Ziska 2011)

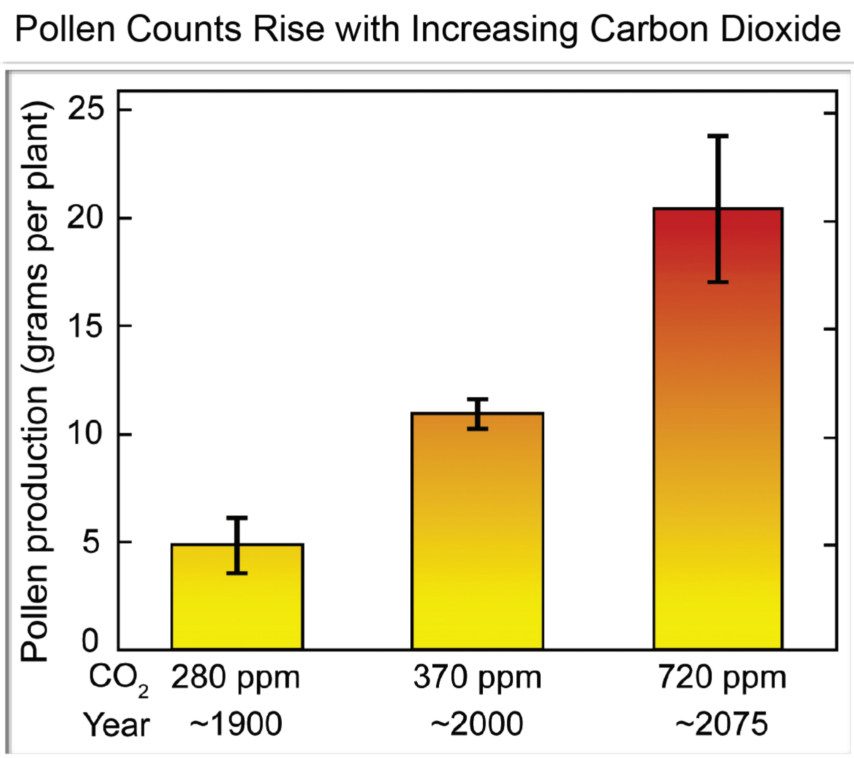

Figure 9.3: Pollen Counts Rise with Increasing Carbon Dioxide

Caption: Pollen production from ragweed grown in chambers at the carbon dioxide concentration of a century ago was about 5 grams per plant; at today's approximate carbon dioxide level, it was about 10 grams, and at a level projected to occur about 2075 under the higher emissions scenario (A2), it was about 20 grams. (Source: Ziska and Caufield 2000a).

Figure 9.4

Caption: Ragweed plant (Photo credit: Lewis Ziska/USDA)

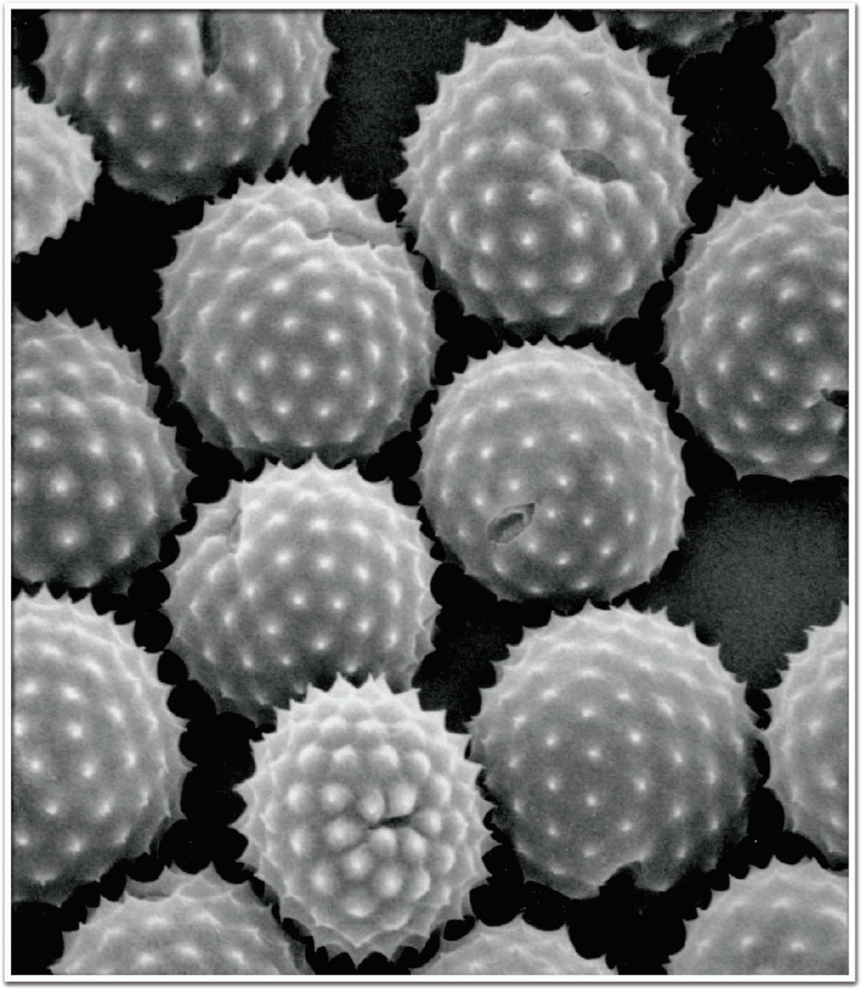

Figure 9.5

Caption: One ragweed plant can produce one billion grains (Rees 1997; Staudt et al. 2010) of allergenic pollen over a season, making it a prime culprit in harming health as temperatures and carbon dioxide levels rise under a changing climate. (Figure source: Lewis Ziska, USDA)

Wildfires

Climate change has already contributed to increasing wildfire frequency (Littell et al. 2009; Mills 2009; Shea et al. 2008; Westerling et al. 2006; Westerling et al. 2011). Wildfire smoke contains particulate matter, carbon monoxide, nitrogen oxides, and various volatile organic compounds (which are ozone precursors) (Akagi et al. 2011) and can significantly reduce air quality, both locally and in areas downwind of fires (Dennekamp and Abramson 2011; Jaffe et al. 2008a; Jaffe et al. 2008b; Pfister et al. 2008; Spracklen et al. 2007). Smoke exposure increases respiratory and cardiovascular hospitalizations, emergency department visits for asthma, bronchitis, chest pain, chronic obstructive pulmonary disease, respiratory infections, and medical visits for lung illnesses, and has been associated with hundreds of thousands of global deaths annually (Delfino et al. 2009; Dennekamp and Abramson 2011; Jenkins et al. 2009; Johnston et al. 2012; Lee et al. 2009). Future climate change is projected to contribute to wildfire risks and associated emissions, with harmful impacts on health (Jacob and Winner 2009; McDonald et al. 2009; Shea et al. 2008; Westerling and Bryant 2008).

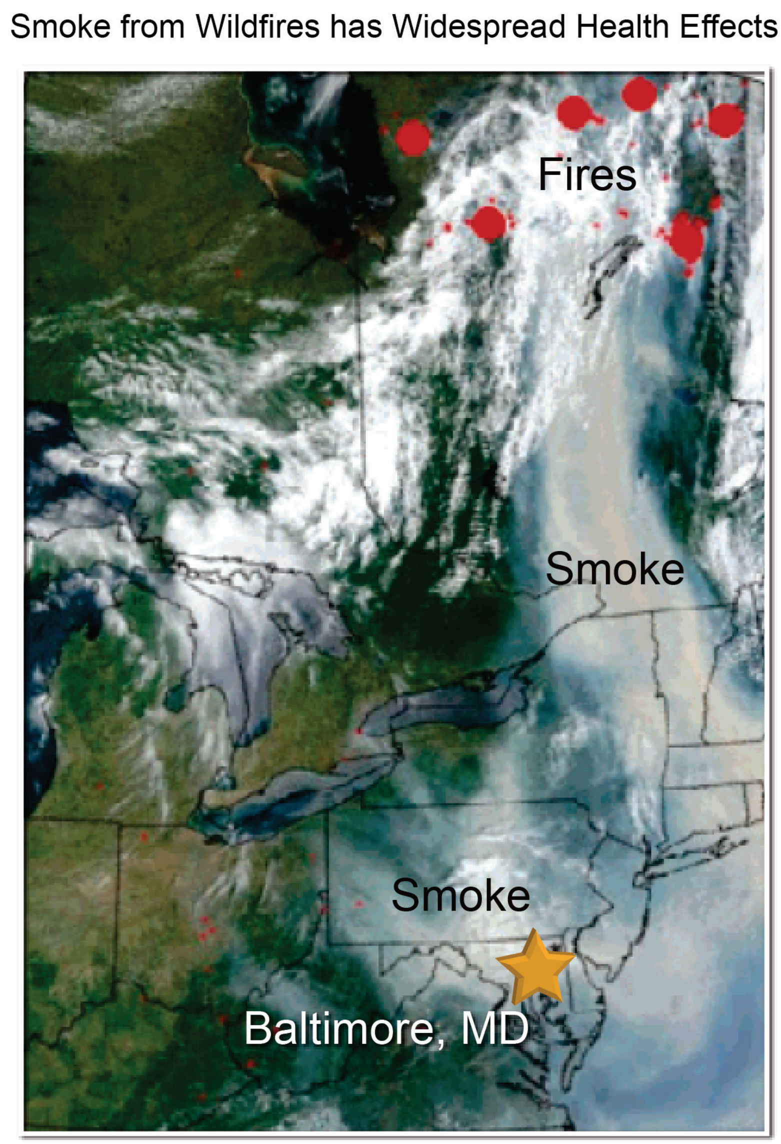

Figure 9.6: Smoke from Wildfires has Widespread Health Effects

Caption: Wildfires, which are increasing in part due to climate change, have health impacts that can extend thousands of miles. Shown here, forest fires in Quebec, Canada during July 2002 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 effect outdoor air quality, but also penetrate indoors (median indoor-to-outdoor ratio 0.91), increasing the long-distance effects of fires on health. The 2012 wildfire season, at almost 9.2 million acres burned, is exceeded only by U.S. wildfires in 2006 when over 9.5 million acres went up in smoke (NCDC 2012). Estimated global deaths from landscape fire smoke have been estimated at 260,000 to 600,000 annually (Johnston et al. 2012). (Source: Kinney (2008). ORIGINAL SOURCE: Sapkota, et al. (2005))

Temperature Extremes

Extreme heat events have long threatened public health in U.S. metropolitan areas (Anderson and Bell 2011; Åström et al. 2011; Ye et al. 2012; Zanobetti et al. 2012). Many cities, including St. Louis, Philadelphia, Chicago, and Cincinnati have sustained dramatic increases in death rates following heat waves. Deaths result from heat stroke and related conditions (Åström et al. 2011; Huang et al. 2011; Li et al. 2012; Ye et al. 2012; Zanobetti et al. 2012), but also from cardiovascular disease, respiratory disease, and cerebrovascular disease (Basu 2009; Rey et al. 2007). Heat waves are also associated with increased hospital admissions for cardiovascular, kidney, and respiratory disorders (Knowlton et al. 2009; Lin et al. 2009; Nitschke et al. 2011; Ostro et al. 2009; Rey et al. 2007). Extreme summer heat is increasing in the U.S. (Duffy and Tebaldi 2012; Ch. 2: Our Changing Climate; Key Message 7), and climate projections indicate that extreme heat events will be more frequent and intense in coming decades (Hayhoe et al. 2010; IPCC 2007; Jackson et al. 2010; Ch. 2: Our Changing Climate; Key Message 7).

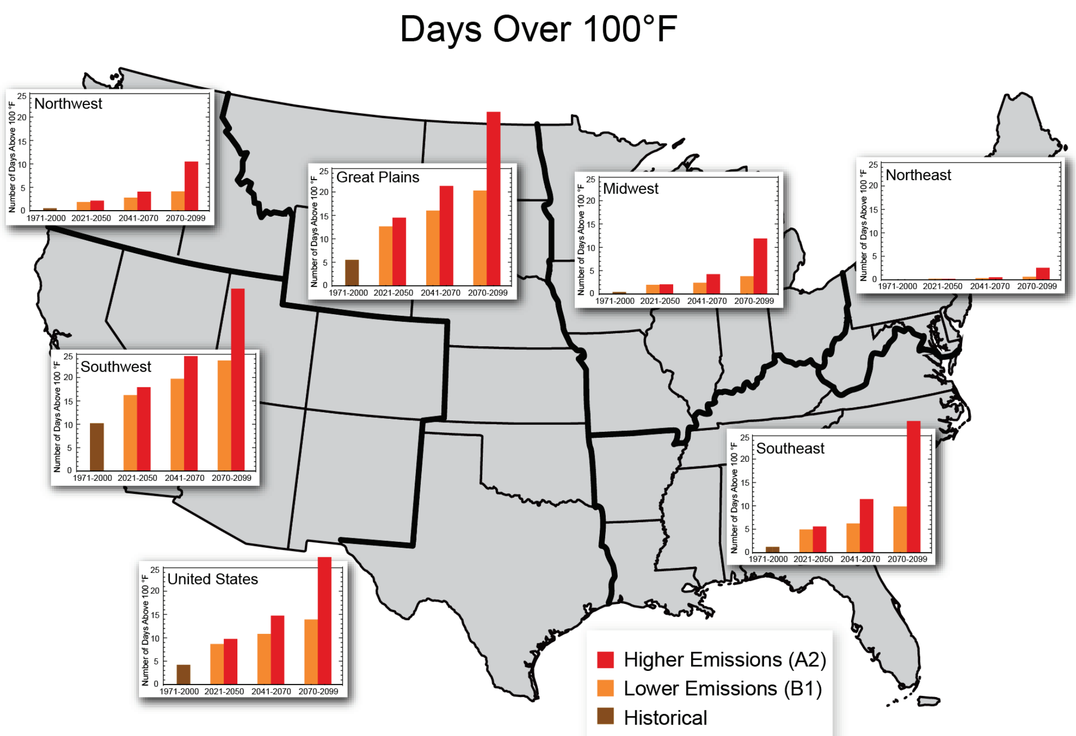

Figure 9.7: Days Over 100°F

Caption: Projected numbers of summer days per year (regional averages) with temperatures greater than 100°F under a lower-emissions scenario in which emissions of heat-trapping gases are substantially reduced (B1) and a higher-emissions scenario in which emissions continue to grow (A2). Historical data are for 1971-2000 (farthest left bar in plots). Projections shown are 30-year averages centered on 2035, 2055, and 2085 (bars left to right). Historical data and projections are data from CMIP3. (Figure source: NOAA NCDC / CICS-NC. Data from CMIP3 Daily Statistically Downscaled.)

Some of the risks of heat-related morbidity and mortality 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 (Barnett 2007; Kalkstein et al. 2011). However, 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 (Johnson et al. 2009; Wilby 2008).

Milder winters resulting from a warming climate can reduce illness, accidents, and deaths associated with cold and snow. Vulnerability to winter weather depends on many non-climate factors, including housing, age, and baseline health (Anderson and Bell 2009; McMichael et al. 2008). While deaths and injuries related to extreme winter weather, such as extreme snow events and ice storms, are projected to decline due to climate change, these reductions are not expected to compensate for the increase in heat-related deaths (Medina-Ramón and Schwartz 2007; Yu et al. 2011).

Extreme Events, Injuries, and Illnesses

The frequency of heavy precipitation events has already increased across the U.S. and is projected to continue to increase (IPCC 2007). Both extreme precipitation and total precipitation have contributed to increases in severe flooding events (see Ch.2: Our Changing Climate). Floods are the second deadliest of all weather-related hazards in the U.S., accounting for approximately 98 deaths per year (Ashley and Ashley 2008), most due to drowning (NOAA 2010). Flash floods and flooding associated with tropical storms result in the highest number of deaths (Ashley and Ashley 2008).

In addition to the immediate health hazards associated with extreme precipitation events, other hazards can often appear once a storm event has passed. Waterborne diseases typically present in the weeks following inundation (Teschke et al. 2010), and water intrusion into buildings, can result in mold contamination that manifests later. Buildings damaged during hurricanes are especially susceptible to water intrusion. Those living in damp indoor environments experience increased prevalence of asthma and other upper respiratory tract symptoms, such as coughing and wheezing (Mendell et al. 2011). See "Heavy Downpour Links to Disease" figure below.

Diseases Carried by Insects and Rodents

The influence of climate change in altering the distribution of diseases borne by insects and rodents remains uncertain. The geographic and seasonal distribution of insect populations, and the diseases they can carry, depend not only on climate, but on land use, socioeconomic and cultural factors, insect control, access to health care, and human responses to disease risk, among other factors (Gage et al. 2008; Hess et al. 2012; Lafferty 2009; Wilson 2009). Climate variability on daily, seasonal, or year-to-year scales can sometimes result in insect/pathogen adaptation and shifts or expansions in their geographic ranges (Lafferty 2009; McGregor 2011; Wilson 2009). Such shifts can alter disease incidence depending on insect-host interaction, host immunity, and pathogen evolution (Epstein 2010; Reiter 2008; Rosenthal 2009; Russell 2009).

North Americans are currently at risk from numerous insect-borne diseases, including Lyme (Diuk-Wasser et al. 2010; Keesing et al. 2009; Mills et al. 2010; Ogden et al. 2008), dengue fever (Degallier et al. 2010; Johansson et al. 2009; Jury 2008; Kolivras 2010; Lambrechts et al.

2011; Ramos et al. 2008), West Nile virus (Gong et al. 2011; Morin and Comrie 2010), and Rocky Mountain spotted fever (Centers for Disease Control and Prevention 2010); invasive insect-borne pathogens, such as chikungunya, Chagas disease, and Rift Valley fever viruses are also threats. Whether higher winter temperatures in the U.S. will create better conditions for locally acquired transmission of diseases like malaria is uncertain, due to infrastructure such as air-conditioning that provides barriers to human-insect contact. Climate change-increased risk in countries where insect-borne diseases are commonly found can also increase susceptibility of North Americans, considering increasing trade with, and travel to, tropical and subtropical areas (McGregor 2011; Wilson 2009).

Box: Transmission Cycle of Lyme Disease

The development and survival of blacklegged ticks, their animal hosts, and the Lyme disease bacterium, *B. 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; 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.

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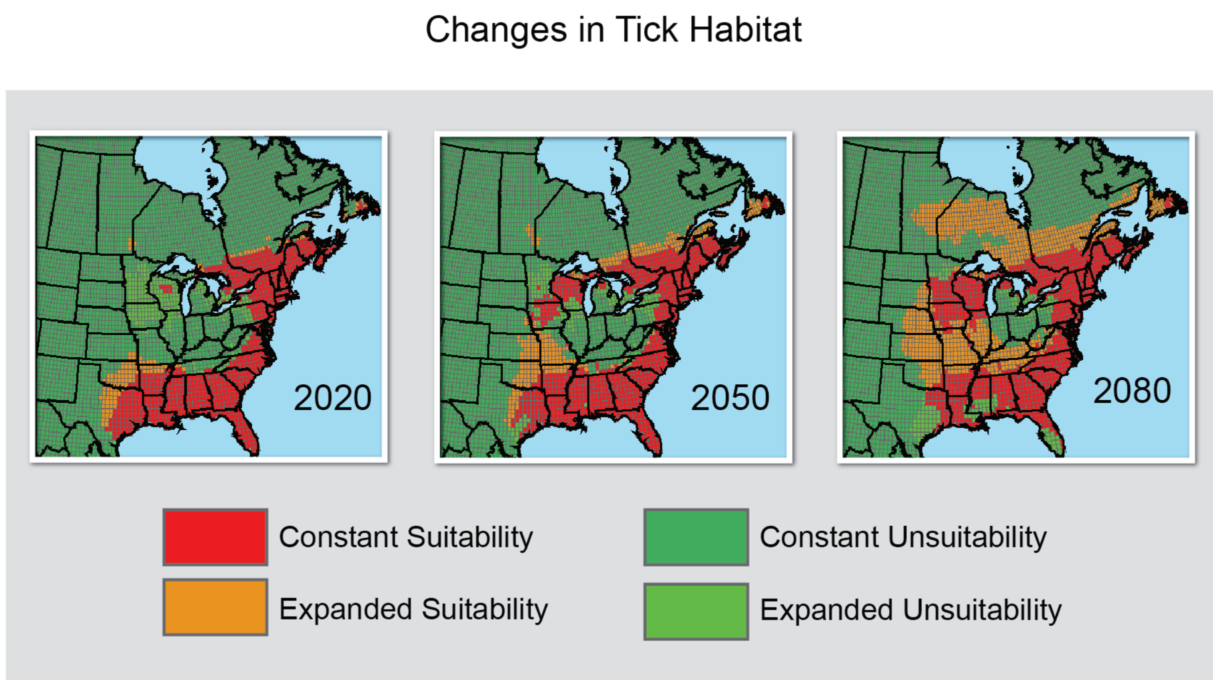

Figure 9.8: Changes in Tick Habitat

Caption: The maps show the projected change in suitable habitat for the tick that transmits Lyme disease for the 2020s, 2050s, and 2080s. The areas in orange are projected to be newly suitable habitat for the tick, with this expansion including Illinois, Kentucky, West Virginia, Tennessee, Arkansas, Missouri, Oklahoma, Kansas, and Nebraska by 2080. Parts of Florida, Mississippi, and Texas are projected to see a reduction in suitable habitat by 2080. (Ogden et al. 2008).

Food- and Waterborne Diarrheal Disease

Diarrheal disease is a major public health issue in developing countries and a persistent concern in the U.S. Exposure to a variety of pathogens in water and food causes diarrheal disease. Seasonality, air and water temperature, precipitation patterns, and extreme rainfall events are all known to affect disease transmission (Curriero et al. 2001; European Centre for Disease Prevention and Control 2012; Semenza et al. 2011). In the U.S., 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, (Fleury et al. 2006; Hall et al. 2011; Hu et al. 2007; Hu et al. 2010; Lipp et al. 2002; Naumova et al. 2007; Onozuka et al. 2010) 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 (Febriani et al. 2010; Nichols et al. 2009). Sporadic increases in streamflow rates, often preceded by rapid snowmelt (Harper et al. 2011) and changes in water treatment (Rizak and Hrudey 2008), have also been shown to precede outbreaks. Risks of waterborne illness and beach closures are expected to increase in the

Great Lakes region due to projected climate change (Patz et al. 2008; Perera et al. 2012).

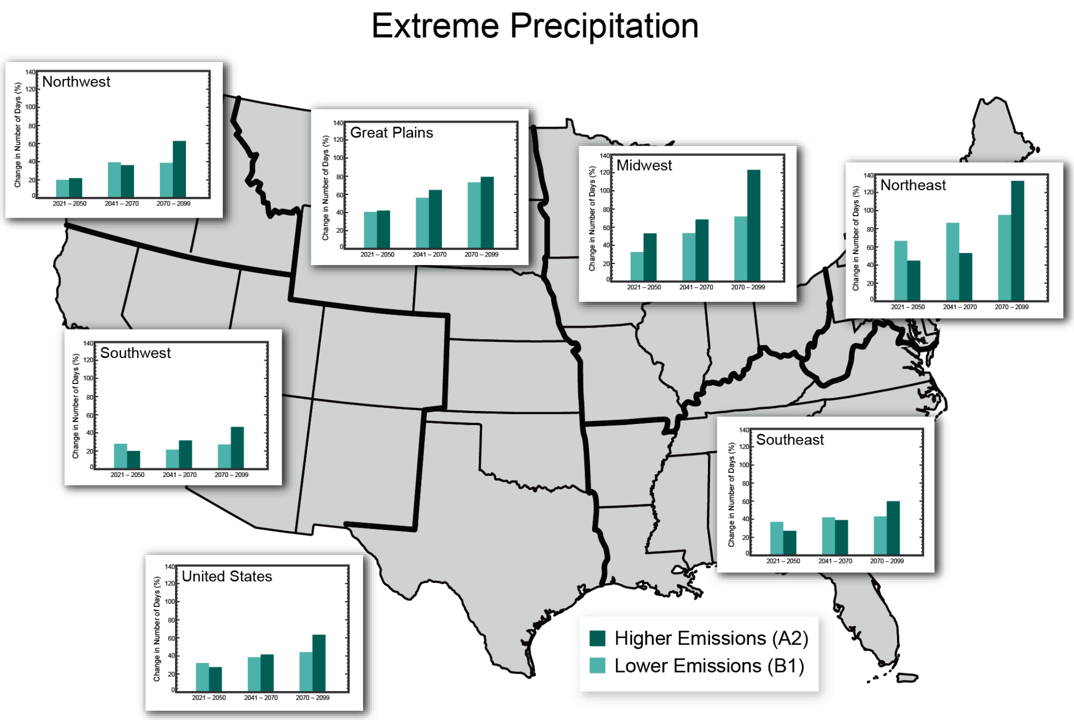

Figure 9.9: Extreme Precipitation

Caption: Projected increases in number of days per year with rainfall greater than 3 inches for 30-year averages centered on 2035, 2055, and 2085 (compared to 1971-2000) assuming a lower-emissions scenario in which emissions of heat-trapping gases are substantially reduced (B1, lighter blue bars on left) and a higher-emissions scenario in which emissions continue to grow (A2, darker bars on right). Waterborne disease outbreaks occur more frequently after extreme rainfall events, so more of these events will increase risks of associated illnesses. (Source: NOAA NCDC / CICS-NC. Data from CMIP3 Daily Statistically Downscaled.)

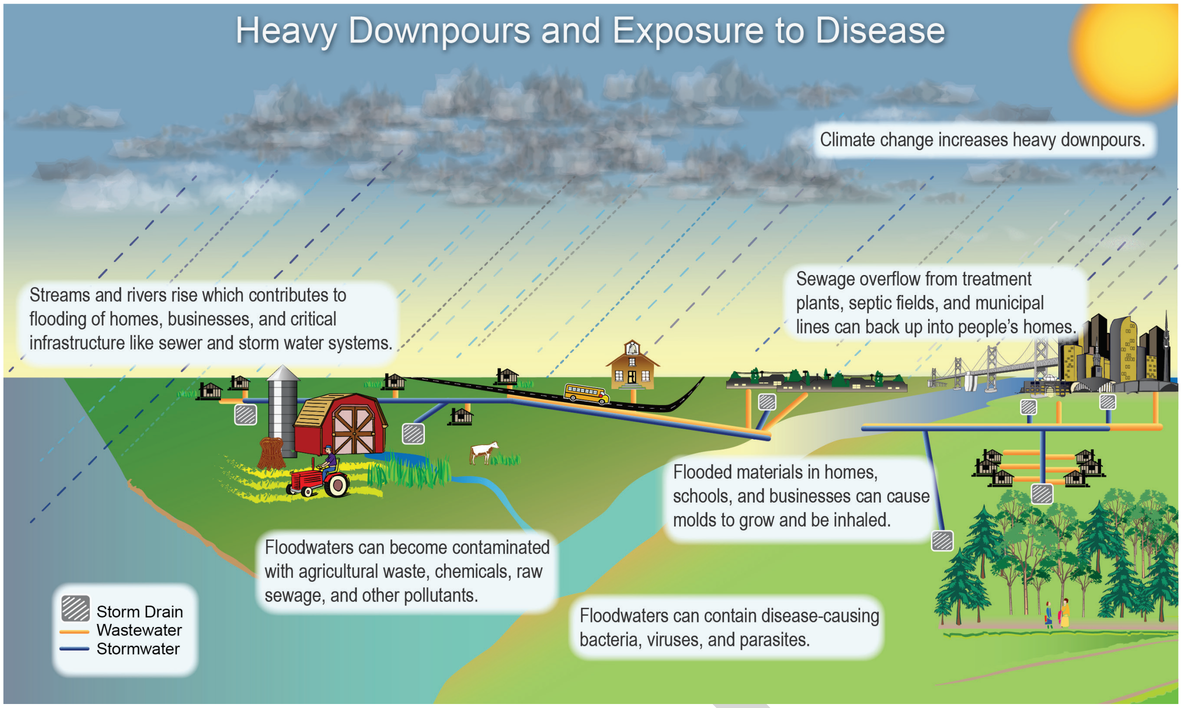

Figure 9.10: Heavy Downpours and Exposure to Disease

Caption: Heavy downpours, which are increasing in much of the U.S., have contributed to increases in heavy flood events (Ch. 2: Our Changing Climate, Key Message 6). The figure above illustrates how humans can become exposed to waterborne diseases, which typically present in the weeks following inundation (Teschke et al. 2010). Human exposures to waterborne diseases can occur via drinking water, as well as recreational waters. (Backer and Moore 2011; Backer et al. 2003; Backer et al. 2005; Backer et al. 2010; Glibert et al. 2005; Moore et al. 2008) (Figure source: NOAA NCDC / CICS-NC.)

Harmful Bloom of Algae

Figure 9.11: Harmful Bloom of Algae

Caption: Remote sensing color image of harmful algal bloom in Lake Erie. 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 (Glibert et al. 2005; Moore et al. 2008). Because algae blooms are closely related to climate factors, projected changes in climate are likely affecting the observed changes in algae blooms. Other factors related to increases in harmful algal blooms include shifts in ocean conditions such as nutrient inputs (Backer and Moore 2011; Moore et al. 2008). (Source: NASA MODIS data provided by R. Stumpf, NOAA)

Food Security

Globally, climate change is expected to threaten both food production and certain aspects of food quality. 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 (Asseng et al. 2011; Battisti and Naylor 2009; Cohen et al. 2008; Gornall et al. 2010; Lobell et al. 2008; Schlenker and Roberts 2009; Schmidhuber and Tubiello 2007; Tubiello et al. 2007; Ziska et al. 2011; Ch. 6: Agriculture; Key Message 6). Livestock and fish production (Hoegh-Guldberg and Bruno 2010; Hoffmann 2010) is also projected to decline. 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 such as pesticides and fertilizers) (Neff et al. 2011).

While the U.S. will be less affected than some other countries (Gregory et al. 2005; Lloyd et al. 2011), the nation will not be immune. Health can be affected in several ways. First, Americans with unique dietary patterns, such as Alaskan natives, will confront shortages of key foods (Brubaker et al. 2011). Second, food insecurity increases with rising food prices (Brown and Funk 2008; Hertel and Rosch 2010). 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 (Bloem et al. 2010). Third, the nutritional value of some foods is projected to decline. Elevated atmospheric CO_2 is associated with decreased nitrogen concentration, and therefore decreased protein, in many crops, such as barley, sorghum, and soy (Högy and Fangmeier 2008; Högy et al. 2009; Taub et al. 2008; Wieser et al. 2008). The nutrient content of crops is also projected to decline, with reduced levels of nutrients such as calcium, iron, zinc, vitamins, and sugars (Idso and Idso 2001). Fourth, farmers are expected to need to use more herbicides and pesticides because of increased growth of pests (Chakraborty and Newton 2011; Garrett et al. 2006; Gregory et al. 2009; Koleva and Schneider 2009) and weeds (Franks et al. 2007; McDonald et al. 2009) as well as with decreased effectiveness (Ziska and Teasdale 2000b) and duration (Bailey 2004) of some of these chemicals. Farmers, farmworkers, and consumers will thus sustain increased exposure to these substances and their residues, which can be toxic.

Mental Health and Stress-related Disorders

Mental illness is one of the major causes of suffering in the U.S., and extreme weather events can affect mental health in several ways (Berry et al. 2008; Berry et al. 2010; Doherty and Clayton 2011; Fritze et al. 2008; Reser and Swim 2011). First, mental health problems are common after disasters (Davidson and McFarlane 2006; Halpern and Tramontin 2007; Mills et al. 2007). For example, research demonstrated high levels of anxiety and post-traumatic stress disorder among people affected by Hurricane Katrina (Galea et al. 2007; Kessler et al. 2008), and similar observations have followed floods (Ahern et al. 2005; Fewtrell and Kay 2008), heat waves (Hansen et al. 2008), and wildfires (McFarlane and Van Hooff 2009) – events increasingly fueled by climate change (see Ch. 2: Our Changing Climate).

Second, some patients with mental illness are especially susceptible to heat (Bouchama et al. 2007; Bulbena et al. 2006). Suicide varies seasonally (Deisenhammer 2003) and rises with hot weather (Maes et al. 1994; Page et al. 2007), suggesting potential climate impacts on depression. Dementia is a risk factor for hospitalization and death during heat waves (Basu and Samet 2002; Hansen et al. 2008). Patients with severe mental illness such as schizophrenia are at risk during hot weather related both to their illness (Cusack et al. 2011; Shiloh et al. 2009; Shiloh et al. 2001) and to their medications (Martin-Latry et al. 2007; Stöllberger et al. 2009). Additional potential mental health impacts, less well understood, include the distress associated with environmental degradation (Albrecht et al. 2007; Higginbotham et al. 2006) and displacement (Loughry 2010; McMichael et al. 2010), and the anxiety and despair that knowledge of climate change might elicit in some people (Doherty and Clayton 2011).

Box: 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 devastating to these populations.

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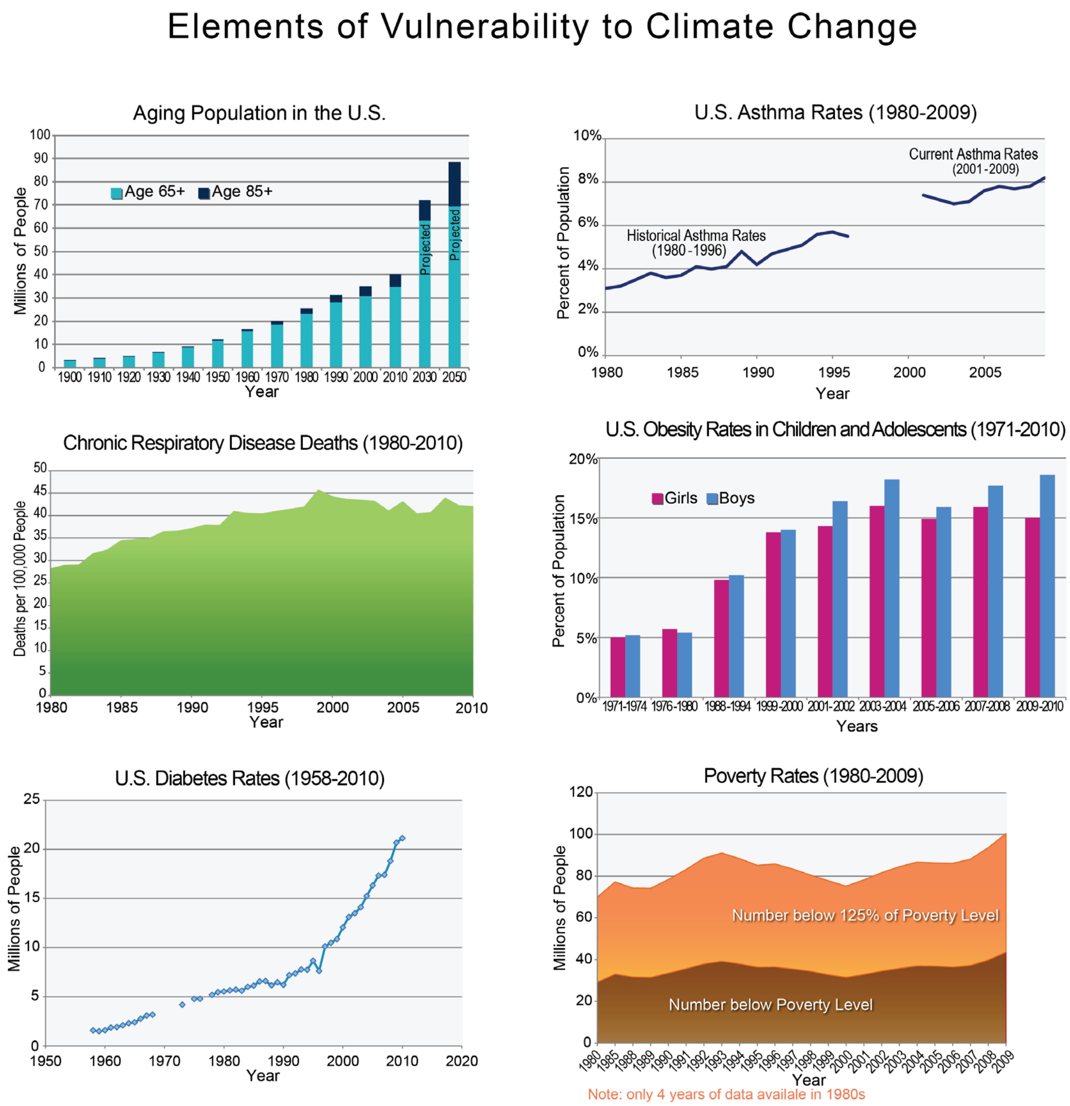

Figure 9.12: Elements of Vulnerability

Caption: A variety of factors can increase the vulnerability of a population to health effects due to climate change. For example, the elderly are more vulnerable to heat stress because their bodies are less able to regulate their temperature. U.S. population trends show rising numbers of elderly. Similarly, people who are obese and/or have diabetes, heart disease, or asthma are 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 various health impacts, so poverty is another increasing risk factor (CDC ; CDC ; Health E-Stat ; U.S. Census Bureau 2010, 2011).

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 subpopulations in the U.S. Children, primarily because of physiology and developmental factors, will disproportionately suffer from the effects of heat waves (Basu 2009), air pollution, infectious illness, and trauma resulting from extreme weather events (AAP 2007; Balbus and Malina 2009; Schmier and Ebi 2009; Sheffield and Landrigan 2011c; Sheffield et al. 2011b). 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 (Balbus and Malina 2009; Basu 2009; Kovats and Hajat 2008; Zanobetti et al. 2012). Pre-existing health conditions also make the elderly susceptible to cardiac and respiratory impacts of air pollution (Reid et al. 2009) and to more severe consequences from infectious diseases (Chou et al. 2010); limited mobility among the elderly can also increase flood-related health risks (Brunkard et al. 2008). 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 (Basu 2009; Reid et al. 2009). 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 (Drewnowski 2009; Lloyd et al. 2011).

Box: Societal System Failures During Extreme Events

We have already seen *multiple system failures* during an extreme weather event in the U.S., as Hurricane Katrina ravaged New Orleans (Lister 2005). Infrastructure and evacuation failures and collapse of critical response services during a storm is one example. Another example is a loss of electrical power during a heat wave (Anderson and Bell 2012). Air conditioning has helped reduce illness and death due to extreme heat (Ostro et al. 2010), but if power is lost, everyone is vulnerable. By their nature, such events can exceed our capacity to respond (Hess et al. 2012). In succession, these events severely deplete our reserves from the personal to the national scale, but disproportionately affect the most vulnerable populations (Shonkoff et al. 2011).

Katrina Refugee Diaspora

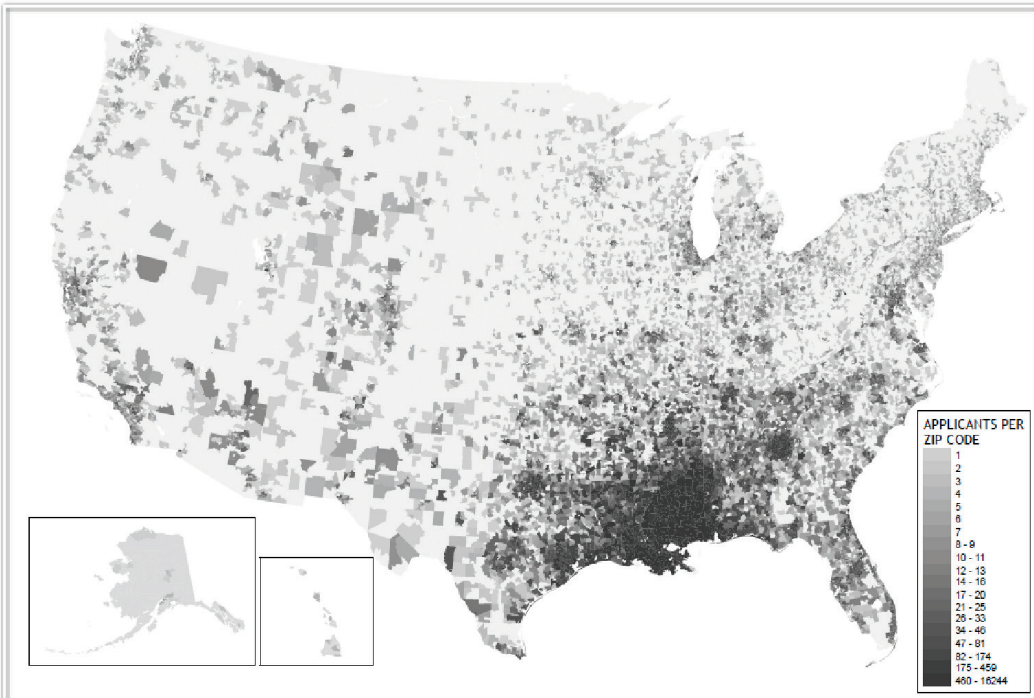

Figure 9.13: Katrina Refugee Diaspora

Caption: This map illustrates the national scope of the dispersion of refugees 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, some of which are projected to increase in frequency and/or intensity as climate continues to change. (Source: Louisiana Geographic Information Center 2005)

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Climate change will disproportionately affect low-income communities (Balbus and Malina 2009; Bullard and Wright 2009b; Frumkin et al. 2008; Harlan et al. 2006; Martinez 2011; O'Neill and Ebi 2009; O'Neill et al. 2008; O’Neill et al. 2003, 2005; Pastor et al. 2006; Shonkoff et al. 2011), raising environmental justice concerns. Existing health disparities (Frumkin et al. 2008; Geronimus et al. 1996; Keppel 2007; National Heart Lung and Blood Institute Working Group 1995; Younger et al. 2008) and other inequities (Bullard et al. 2011; National Urban League 2009) 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 had difficulty evacuating and recovering from the storm (Bullard and Wright 2009b; Pastor et al. 2006). Other climate change related issues that have an equity component include heat waves and air quality (Bullard and Wright 2009b; Harlan et al. 2006; Martinez 2011; O'Neill et al. 2008; O’Neill et al. 2005; Shonkoff et al. 2011).

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 population health impacts associated with climate change can be prevented through early action at significantly lower cost than dealing with them after they occur (Ebi et al. 2003; Frumkin et al. 2008). Early prevention, such as early warnings for extreme weather, can be particularly cost-effective (Chokshi and Farley 2012; Kosatsky 2005; Rhodes et al. 2010; The Community Preventitive Services Task Force 2012). As with many illnesses (Sherwood and Huber 2010), once impacts are apparent, even the best adaptive efforts can be overwhelmed, and damage control becomes the priority (IPCC 2012).

Box: 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 (IOM 2008). Factors include shifting ranges of disease-carrying pests, lack of population immunity and preparedness, and inadequate disease monitoring. Diseases including Lyme disease and dengue fever pose increasing health threats to the U.S. population. The public health system is not currently prepared to monitor or respond to these growing disease risks. Introduction of a new disease, such as Chikungunya, has devastated populations in other countries around the world (Anyamba et al. 2012; Dwibedi et al. 2011; Rezza et al. 2007).

-- end box --

The value of prevention is most apparent with activities that reduce carbon pollution, such as reliance on alternative energy sources for electricity production (Markandya et al. 2009) and more efficient and active transport such as biking or walking (Woodcock et al. 2009). Many such options have immediate public health benefits, such as lower rates of obesity, diabetes, and heart disease, and also reduce adverse climate-health impacts, producing cost savings in the near- and longer-term (Haines et al. 2009). The relationship holds for other types of prevention for exposures from climate change that are already apparent. For instance, heat wave early warning systems protect vulnerable populations 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.

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, Americans don't mention health impacts, (Smith and Leiserowitz 2012) and when asked about health impacts specifically, most believe it will affect people in a different time or place (Leiserowitz 2005). 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 (Maibach et al. 2010).

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 (Ebi et al. 2006). 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 is decreasing: health insurance coverage has been declining (DeNavas-Walt et al. 2011), the number of hospital emergency departments is dropping (Hsia et al. 2011), and funding for public health programming is increasingly limited. 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, especially with shortages of health care and public health professionals projected by 2020 (Derksen and Whelan 2009; Johnson 2008) . Without careful consideration of how to prevent future impacts, similar patterns could emerge regarding the health impacts from climate change.

There are public health programs in some locations that address climate-sensitive health issues, and integrating such programs into the mainstream as adaptation needs increase would improve public health resilience to climate change (Ebi et al. 2009). Given that these programs have demonstrated efficacy against current threats that are expected to worsen, it is prudent to expand investment in these programs now (Frumkin et al. 2008). Climate change preparedness activities and climate-health research are significantly underfunded (Ebi et al. 2006), but there is an opportunity to address this shortfall before needs become more widespread.

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 affect human health. Some of these efforts will benefit health, but some could potentially be harmful. 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 (Haines et al. 2009).

Much of the focus of health co-benefits has been on reducing health-harming air pollution (Bell et al. 2008; Markandya et al. 2009; Nemet et al. 2010; Shindell et al. 2011; Wilkinson et al. 2009; Woodcock et al. 2009). One study projects that eliminating short motor vehicle trips in 11 Midwestern metropolitan areas, and instead replacing 50% of those motor vehicle trips with bicycle use, would avoid nearly 1,300 deaths and create up to $8 billion dollars in health benefits annually for the upper Midwest region (Grabow et al. 2012). 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 (Bambrick et al. 2011; Kjellstrom and Weaver 2009; Parker 2011; Patz et al. 2008).

Innovative urban design could create increased access to active transport (Patz et al. 2008). 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 (Bambrick et al. 2011; Wilkinson et al. 2007). Urban planning and design could produce additional societal co-benefits by promoting social interaction and prioritizing vulnerable urban populations (Bambrick et al. 2011).

Strategies to reduce heat-trapping gas emissions can also produce immediate health benefits through means other than air pollution reductions. One example is a reduction in red meat consumption. Emissions of methane from livestock production account for 20% of the U.S. total (McMichael et al. 2007; Parker 2011). While there are several means to reduce methane emissions, a reduction achieved through an overall decrease in the consumption, and therefore production, of red meat could have near-term health benefits (Parker 2011) that include a reduction in cardiovascular disease and the occurrence of some cancers (Friel 2010; Friel et al. 2009).

Climate change mitigation and adaptation policy could also reduce health-related disparities between wealthy and poor communities, yielding positive equity impacts (Luber and Prudent 2009). Several studies have found that communities of color and poor communities experience disproportionately high exposures to air pollution (Ash et al. 2009; Pastor et al. 2004; Pellizzari et al. 1999; Perlin et al. 1995; Wernette and Nieves 1992). 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 identifiable populations (like new immigrant communities) are more vulnerable to the adverse effects of extreme weather events (Pastor et al. 2009). These vulnerable populations could benefit from urban planning policies that ensure that new buildings, including homes, are constructed to resist extreme weather events (Bambrick et al. 2011).

Policies to reduce climate change also have the potential to improve the food security of low-income residents by preventing decreased crop production due to climate change, thereby avoiding associated increases in food prices.

Traceable Accounts

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Key Message Process: 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 (Balbus and Malina 2009), workshop reports for the northwestern and Southeastern U.S. and additional technical inputs on a variety of topics.

Key message #1/4	**Climate change threatens human health and well-being in many ways, including impacts from increased extreme weather events, wildfire, decreased air quality, diseases transmitted by insects, food and water, and threats to mental health. Some of these health impacts are already underway in the U.S.**
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 (Balbus and Malina 2009) and workshop reports for the NW and SE U.S. 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 air quality on human health have been well documented concerning projected increases in ozone (Bell et al. 2008; Bell et al. 2007; Chang et al. 2010; Ebi and Semenza 2008; Jacob and Winner 2009; Kjellstrom et al. 2010; Liao et al. 2009; Spickett et al. 2011; Tagaris et al. 2007), which leads to a number of health impacts (Dennekamp and Carey 2010; Kampa and Castanas 2008; Kinney 2008). **Allergens:** The effects of increased temperatures and atmospheric CO2 concentration has been documented with studies showing that reduced health will result from increased exposure to aeroallergens (Ariano et al. 2010; Breton et al. 2006; D'amato and Cecchi 2008; Emberlin et al. 2002; Pinkerton et al. 2012; Reid and Gamble 2009; Schmier and Ebi 2009; Shea et al. 2008; Sheffield and Landrigan 2011c; Sheffield et al. 2011a; Staudt et al. 2010; Ziska 2011) **Wildfire:** The effects of wildfire on human health have been well documented with the increase in frequency (Jacob and Winner 2009; Littell et al. 2009; MacDonald 2010; Mills 2009; Shea et al. 2008; Westerling and Bryant 2008; Westerling et al. 2006; Westerling et al. 2011) leading to decreased air quality (Akagi et al. 2011; Dennekamp and Abramson 2011; Jaffe et al. 2008a; Jaffe et al. 2008b; Pfister et al. 2008; Spracklen et al. 2007) and negative health impacts (Delfino et al. 2009; Dennekamp and Abramson 2011; Jenkins et al. 2009; Lee et al. 2009). **Temperature Extremes:** The effects of temperature extremes on human health have been well documented for increased heat waves (Duffy and Tebaldi 2012; Hayhoe et al. 2010; IPCC 2007; Jackson et al. 2010), which cause more deaths (Basu 2009; Rey et al. 2007), hospital admissions (Lin et al. 2009; Nitschke et al. 2011; Ostro et al. 2009) and population

vulnerability (Johnson et al. 2009; Wilby 2008)

Extreme Weather Events:
The effects of weather extremes on human health have been well documented, particularly for increased heavy precipitation, which leads to more deaths (Ashley and Ashley 2008; NOAA 2010), waterborne diseases (Teschke et al. 2010), and illness (Mendell et al. 2011).

Diseases from Insects and Rodents:
The effects of climate change on diseases transmitted by insect and rodents (vector-borne and zoonotic diseases) have been documented in a number of publications. Studies have explored the effects climate change have on location and adaptation of insects (Lafferty 2009; McGregor 2011; Tabachnick 2010), which can alter their interaction and effect with human health (Epstein 2010; Reiter 2008; Rosenthal 2009; Russell 2009), and have documented a number of insect-borne diseases affect the U.S. (Centers for Disease Control and Prevention 2010; Degallier et al. 2010; Diuk-Wasser et al. 2010; Gong et al. 2011; Johansson et al. 2009; Jury 2008; Keesing et al. 2009; Kolivras 2010; Lambrechts et al. 2011; Mills et al. 2010; Morin and Comrie 2010; Ogden et al. 2008; Ramos et al. 2008). 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 U.S.

Food- and Waterborne Disease:
There has been extensive research concerning the climate change effects on water- and food-borne disease transmission (Febriani et al. 2010; Fleury et al. 2006; Harper et al. 2011; Hu et al. 2007; Hu et al. 2010; Lipp et al. 2002; Naumova et al. 2007; Nichols et al. 2009; Onozuka et al. 2010; Rizak and Hrudey 2008; Semenza et al. 2011). The current evidence base strongly supports that waterborne diarrheal disease is both seasonal and sensitive to climate variability. There are also multiple studies associating extreme precipitation events with waterborne disease outbreaks (Curriero et al. 2001). This evidence of responsiveness to weather and climate, combined with evidence strongly suggesting that temperatures will increase and extreme precipitation events will increase in frequency and severity, 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 climatologic evidence for increasing frequency and intensity of extreme precipitation events in the future. The scientific literature modeling 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 disease.

Harmful Algal Blooms:
The effects of biogenic systems on human health has been extensively studied with showing that reduced health will result from increased spread and frequency of harmful algae blooms (Backer and Moore 2011; Glibert et al. 2005; Moore et al. 2008), which have multiple exposure routes (Backer et al. 2003; Backer et al. 2005; Backer et al. 2010). Additional studies have shown extreme rainfall and higher temperatures leads to higher fungi and mold health concerns (Fisk et al. 2007; IOM 2011; Mudarri and Fisk 2007; Wolf et al. 2010).

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 is an area of active research (Asseng et al. 2011; Battisti and

	Naylor 2009; Cohen et al. 2008; Gornall et al. 2010; Lobell et al. 2008; Schlenker and Roberts 2009; Schmidhuber and Tubiello 2007; Tubiello et al. 2007; Ziska et al. 2011; Ch. 6: Agriculture; Key Message on Food Security). While the U.S. as a whole will be less affected than some other countries, the most vulnerable, including those dependent on subsistence lifestyles, especially as Alaskan natives, will not be immune. **Threats to Mental Health:** The effects of climate change on mental health have been extensively studied (Berry et al. 2008; Doherty and Clayton 2011; Fritze et al. 2008; Reser and Swim 2011). Studies have shown the impacts of mental health problems caused after disasters (Davidson and McFarlane 2006; Halpern and Tramontin 2007; Mills et al. 2007), with extreme events like Hurricane Katrina (Galea et al. 2007; Kessler et al. 2008), floods (Ahern et al. 2005; Fewtrell and Kay 2008), heat waves (Hansen et al. 2008), and wildfires (McFarlane and Van Hooff 2009) have lead to mental health problems. Further work has shown that people with mental illnesses are increasingly vulnerable under heat waves, which are linked to suicide (Deisenhammer 2003; Maes et al. 1994; Page et al. 2007), increased hospitalization and death for dementia patients (Basu and Samet 2002; Hansen et al. 2008) , increased risk for schizophrenia patients (Cusack et al. 2011; Martin-Latry et al. 2007; Shiloh et al. 2009; Shiloh et al. 2001; Stöllberger et al. 2009), and a number of other mental illnesses (Albrecht et al. 2007; Doherty and Clayton 2011; Fritze et al. 2008; Higginbotham et al. 2006; Loughry 2010; McMichael et al. 2010).
New information and remaining uncertainties	Important new evidence on heat-health effects (Åström et al. 2011; Ye et al. 2012; Zanobetti et al. 2012) 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 U.S. 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 adaptive capacity of public health systems to prepare in advance for the health effects of climate change, and prevent the degree of harm to individual and community health, and limit associated health burdens and societal costs. Decreased Air Quality: **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** confidence. 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.

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

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Key Message Process: See process for Key Message #1

Key message #2/4	**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 (Balbus and Malina 2009) (Balbus, 2012) and workshop reports for the NW and SE U.S. (Schramm, 2012) Nearly 60 additional technical inputs related to human health were received and reviewed as part of the Federal Register Notice solicitation for public input. **Amplification of existing health threats**: The effects of extreme heat and heat waves; 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 likely to exacerbate these health effects in the future (IPCC SREX 2012). **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 (Duffy and Tebaldi 2012; Hayhoe et al. 2010; Jackson et al. 2010; Schmier and Ebi 2009; Shea 2007; Sheffield et al. 2011a). Extreme heat also causes more pediatric deaths (Basu 2009; Rey et al. 2007), more emergency room visits and hospital admissions (Knowlton et al. 2009; Lin et al. 2009; Nitschke et al. 2011; Ostro et al. 2009). More adverse effects from increased heavy precipitation can lead to more pediatric deaths, waterborne diseases (Teschke et al. 2010), and illness (Mendell 2007). **The elderly:** Heat stress is especially damaging to the health of older people (Balbus and Malina 2009; Basu and Samet 2002; Knowlton et al. 2009; Kovats and Hajat 2008; Medina-Ramón and Schwartz 2007; Zanobetti et al. 2012); as are climate-sensitive increases in air pollution (Centers for Disease Control and Prevention 2010). **The sick:** People and communities lacking the resources to adapt, to enhance mobility and escape health-sensitive situations, are at relatively high risk (Harlan et al. 2006). Climate change will disproportionately impact low-income communities and some communities of color, raising environmental justice concern (Balbus and Malina 2009; Frumkin et al. 2008; Geronimus et al. 1996; Harlan et al. 2006; Keppel 2007; National Heart Lung and Blood Institute Working Group 1995; O'Neill et al. 2008; O'Neill et al. 2003; O’Neill et al. 2005; Pastor et al. 2006; Shonkoff et al. 2011; Uejio et al. 2011 (Bullard and Wright 2009a) Existing health disparities {Frumkin, 2008 #6444; Younger et al. 2008) and other inequities (Bullard et al. 2011; National Urban League 2009) 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 had difficulty evacuating and recovering from the storm (Bullard and Wright 2009b; Pastor et al. 2006). Other climate change-related issues that have an equity component include heat waves and air quality (Balbus and Malina 2009; Harlan et al. 2006; O'Neill et al. 2008; O'Neill et al. 2003; O’Neill et al. 2005;

	Shonkoff et al. 2011). **The poor:** People and communities lacking the resources to adapt, to enhance mobility and escape health-sensitive situations, are at relatively high risk (Harlan et al. 2006). Climate change will disproportionately impact low-income communities and some communities of color, raising environmental justice concern (Balbus and Malina 2009; Bullard et al. 2011; Frumkin 2002; Harlan et al. 2006; O'Neill et al. 2008; O'Neill et al. 2003; O'Neill et al. 2005; Pastor et al. 2006; Shonkoff et al. 2011; Uejio et al. 2011; White-Newsome et al. 2009). Existing health disparities (Frumkin et al. 2008; Geronimus et al. 1996; Keppel 2007; National Heart Lung and Blood Institute Working Group 1995; Younger et al. 2008) and other inequities (Bullard et al. 2011; National Urban League 2009) 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 had difficulty evacuating and recovering from the storm (Bullard and Wright 2009b; Pastor et al. 2006) . Other climate change-related issues that have an equity component include heat waves and air quality (Balbus and Malina 2009; Harlan et al. 2006; O'Neill et al. 2008; O'Neill et al. 2003; O'Neill et al. 2005; Shonkoff et al. 2011). **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 i.e. air conditioning use (O'Neill et al. 2005; Shonkoff et al. 2011; Uejio et al. 2011; White-Newsome et al. 2009). There are also racial disparities in withstanding, and recovering from, extreme weather events (Bullard and Wright 2009b; Pastor et al. 2006). Current epidemiological evidence on the climate-sensitive health outcomes in the U.S. indicate 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 confer vulnerability (age, socioeconomic status, race) as well as attributes of place that modulate or amplify exposure (flood-plain, coastal zone, urban heat island), as well as the resilience of critical public health infrastructure.
New information and remaining uncertainties	Important new evidence (Zanobetti et al. 2012) confirmed findings from a prior literature review. Due to uncertainties in rates of adaptation, and implementation of public health interventions that aim to address underlying health disparities and determinants of health, 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 (Luber and Prudent 2009). We haven't yet had frequent opportunities as a public health community to evaluate the overall success and successful elements of adaptation interventions.
Assessment of confidence based on evidence	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**.

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

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Key Message Process: See process for Key Message #1

Key message #3/4	**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 (Balbus and Malina 2009) and workshop reports for the NW and SE U.S. 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 prevention activities, like using alternative energy sources (Markandya et al. 2009) and using active transportation like biking or walking (Grabow et al. 2012; Woodcock et al. 2009), can lead to significant public health benefits, which can save costs in the near and long term (Haines et al. 2009). For example, a study performed by Ebi et al. (Ebi et al. 2003) reports that heat wave early warning systems are cheaper than treating heat related illnesses. There are also publications on existing programs that have improved public health resilience (Ebi and Semenza 2008; Frumkin et al. 2008). However, studies have shown that factors such as determining what type of prevention to invest in (Ebi et al. 2006), underfunding of climate-health research and preparedness activities (Ebi et al. 2009), and the declining health care system (DeNavas-Walt et al. 2011; Hsia et al. 2011) will inhibit our prevention potential. The cost-effectiveness of many prevention activities is well established (Derksen and Whelan 2009). Some preventive actions are cost saving, while others are deemed cost-effective based on a pre-determined threshold, and overall a larger proportion of effective prevention efforts are cost-saving compared with clinical interventions that address disease once symptoms are manifest (Chokshi and Farley 2012). There is less information on the cost-effectiveness of specific prevention interventions relevant to climate sensitive health threats (e.g. heat early warning systems), however. Overall, we thus have high confidence for this portion of the message. 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 wave of 2003, illustrate this relationship well (Kosatsky 2005; Rhodes et al. 2010). 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 (IPCC 2012; Rezza et al. 2007). This is equally true of the public health sector, specifically, leading to very high confidence in this statement.
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 susceptibility, and the capacities to adapt that are available at each scale. Currently the capacity of the American public health and health care delivery systems are decreasing, making the U.S. population even more vulnerable (Derksen and Whelan 2009; Johnson et al. 2009). 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: **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 evaluation information from preparedness plans post-implementation. **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 (Ebi et al. 2003). **Very high**: Our ability to adapt to future changes may be limited.

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

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Key Message Process: See process for Key Message #1

Key message #4/4	**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.**
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 (Balbus and Malina 2009) and workshop reports for the NW and SE U.S. (Schramm, 2012) 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 (Haines et al. 2009), with many recent publications illustrating the benefit of reduced air pollution (Bell et al. 2008; Markandya et al. 2009; Nemet et al. 2010; Shindell et al. 2011; Smith and Haigler 2008; Wilkinson et al. 2009; Woodcock et al. 2009). Additionally, some studies have looked at the co-benefits to climate change and health by applying innovative urban design practices which includes to reduce energy consumption and pollution while increasing public health (Bambrick et al. 2011; Grabow et al. 2012; Kjellstrom and Weaver 2009; Patz et al. 2008), and decreased vulnerability of communities to extreme events (Bambrick et al. 2011; Pastor et al. 2009) and the disparity between different societal groups (Ash et al. 2009; Luber and Prudent 2009; Pastor et al. 2004; Pellizzari et al. 1999; Perlin et al. 1995; Wernette and Nieves 1992). Even something as simple as eating less red meat has been reported to combat climate change (Kjellstrom and Weaver 2009; McMichael et al. 2007; Parker 2011) and improve health (Friel 2010; Friel et al. 2009; Parker 2011).
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.
Assessment of confidence based on evidence	**Very high**

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

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