



THE IMPACTS OF CLIMATE CHANGE ON **HUMAN HEALTH** IN THE UNITED STATES

A Scientific Assessment

U.S. Global Change Research Program

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April 2016

Dear Colleagues:

On behalf of the National Science and Technology Council and the U.S. Global Change Research Program, I am pleased to share this report, *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*. It advances scientific understanding of the impacts of climate change on public health, highlights social and environmental disparities that make some communities particularly vulnerable to climate change, and confirms that climate change is a significant threat to the health of all Americans.

This report was developed by over 100 experts from across the Nation representing eight Federal agencies. I want to thank in particular the efforts of the U.S. Environmental Protection Agency (EPA), the U.S. Department of Health and Human Services (HHS), and the National Oceanic and Atmospheric Administration (NOAA) for leading in the development of this report. It was called for under the President's Climate Action Plan and is a major contribution to the sustained National Climate Assessment process. The report was informed by input gathered in listening sessions and scientific and technical information contributed through open solicitations. It underwent rigorous reviews by the public and by scientific experts inside and outside of the government, including a special committee of the National Academies of Sciences, Engineering, and Medicine.

I applaud the authors, reviewers, and staff who have developed this scientific assessment. Their dedication over the past three years has been remarkable and their work has advanced our knowledge of how human health is impacted by climate change now and in the future.

Combating the health threats from climate change is a top priority for President Obama and a key driver of his Climate Action Plan. I strongly and respectfully urge decision makers across the Nation to use the scientific information contained within to take action and protect the health of current and future generations.

A handwritten signature in black ink that reads "John P. Holdren".

Dr. John P. Holdren

Assistant to the President for Science and Technology

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THE IMPACTS OF CLIMATE CHANGE ON HUMAN HEALTH IN THE UNITED STATES

A Scientific Assessment

About the USGCRP Climate and Health Assessment

The U.S. Global Change Research Program (USGCRP) Climate and Health Assessment has been developed to enhance understanding and inform decisions about the growing threat of climate change to the health and well-being of residents of the United States. This scientific assessment is part of the ongoing efforts of USGCRP's sustained National Climate Assessment (NCA) process and was called for under the President's Climate Action Plan.¹ USGCRP agencies identified human health impacts as a high-priority topic for scientific assessment.

This assessment was developed by a team of more than 100 experts from 8 U.S. Federal agencies (including employees, contractors, and affiliates) to inform public health officials, urban and disaster response planners, decision makers, and other stakeholders within and outside of government who are interested in better understanding the risks climate change presents to human health.

The USGCRP Climate and Health Assessment draws from a large body of scientific peer-reviewed research and other publicly available sources; all sources meet the standards of the Information Quality Act (IQA). The report was extensively reviewed by the public and experts, including a committee of the National Academies of Sciences, Engineering, and Medicine,² the 13 Federal agencies of the U.S. Global Change Research Program, and the Federal Committee on Environment, Natural Resources, and Sustainability (CENRS).

About the National Climate Assessment

The Third National Climate Assessment (2014 NCA)³ assessed the science of climate change and its impacts across the United States, now and throughout this century. The report documents climate change related impacts and responses for various sectors and regions, with the goal of better informing public and private decision making at all levels. The 2014 NCA included a chapter on human health impacts,⁴ which formed the foundation for the development of this assessment.



EXECUTIVE SUMMARY

Climate change threatens human health and well-being in the United States. The U.S. Global Change Research Program (USGCRP) Climate and Health Assessment has been developed to enhance understanding and inform decisions about this growing threat. This scientific assessment, called for under the President's Climate Action Plan, is a major report of the sustained National Climate Assessment (NCA) process. The report responds to the 1990 Congressional mandate to assist the Nation in understanding, assessing, predicting, and responding to human-induced and natural processes of global change. The agencies of the USGCRP identified human health impacts as a high-priority topic for scientific assessment.

The purpose of this assessment is to provide a comprehensive, evidence-based, and, where possible, quantitative estimation of observed and projected climate change related health impacts in the United States. The USGCRP Climate and Health Assessment has been developed to inform public health officials, urban and disaster response planners, decision makers, and other stakeholders within and outside of government who are interested in better understanding the risks climate change presents to human health.

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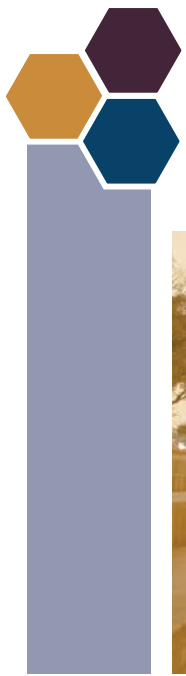
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Executive Summary of **THE IMPACTS OF CLIMATE CHANGE ON HUMAN HEALTH IN THE UNITED STATES**



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Climate change is a significant threat to the health of the American people. The impacts of human-induced climate change are increasing nationwide. Rising greenhouse gas concentrations result in increases in temperature, changes in precipitation, increases in the frequency and intensity of some extreme weather events, and rising sea levels. These climate change impacts endanger our health by affecting our food and water sources, the air we breathe, the weather we experience, and our interactions with the built and natural environments. As the climate continues to change, the risks to human health continue to grow.

Current and future climate impacts expose more people in more places to public health threats. Already in the United States, we have observed climate-related increases in our exposure to elevated temperatures; more frequent, severe, or longer-lasting extreme events; degraded air quality; diseases transmitted through food, water, and disease vectors (such as ticks and mosquitoes); and stresses to our mental health and well-being.

Almost all of these threats are expected to worsen with continued climate change. Some of these health threats will occur over longer time periods, or at unprecedented times of the year; some people will be exposed to threats not previously experienced in their locations. Overall, instances of potentially beneficial health impacts of climate change are limited in number and pertain to specific regions or populations. For example, the reduction in cold-related deaths is projected to be smaller than the increase in heat-related deaths in most regions.

Every American is vulnerable to the health impacts associated with climate change. Increased exposure to multiple health threats, together with changes in sensitivity and the ability to adapt to those threats, increases a person's vulnerability to climate-related health effects. The impacts of climate change on human health interact with underlying health, demographic, and socioeconomic factors. Through the combined influence of these factors, climate change exacerbates some existing health threats and creates new public health challenges. While all Americans are at risk, some populations are disproportionately vulnerable, including those with low income, some communities of color, immigrant groups (including those with limited English proficiency), Indigenous peoples, children and pregnant women, older adults, vulnerable occupational groups, persons with disabilities, and persons with preexisting or chronic medical conditions.



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Changes in aquatic habitats and species may affect subsistence fishing among Indigenous populations.

In recent years, scientific understanding of how climate change increases risks to human health has advanced significantly. Even so, the ability to evaluate, monitor, and project health effects varies across climate impacts. For instance, information on health outcomes differs in terms of whether complete, long-term datasets exist that allow quantification of observed changes, and whether existing models can project impacts at the timescales and geographic scales of interest. Differences also exist in the metrics available for observing or projecting different health impacts. For some health impacts, the available metrics only describe changes in risk of exposure, while for others, metrics describe changes in actual health outcomes (such as the number of new cases of a disease or an increase in deaths).

This assessment strengthens and expands our understanding of climate-related health impacts by providing a more definitive description of climate-related health burdens in the United States. It builds on the 2014 National Climate Assessment¹ and reviews and synthesizes key contributions to the published literature. Acknowledging the rising demand for data that can be used to characterize how climate change affects health, this report assesses recent analyses that quantify observed and projected health impacts. Each chapter characterizes the strength of the scientific evidence for a given climate–health exposure pathway or “link” in the

Every American is vulnerable to the health impacts associated with climate change



While all Americans are at risk, some populations are disproportionately vulnerable, including children and pregnant women.

causal chain between a climate change impact and its associated health outcome. This assessment’s findings represent an improvement in scientific confidence in the link between

climate change and a broad range of threats to public health, while recognizing populations of concern and identifying emerging issues. These considerations provide the context for understanding Americans’ changing

health risks and allow us to identify, project, and respond to future climate change health threats. The overall findings underscore the significance of the growing risk climate change poses to human health in the United States.



Los Angeles, California, May 22, 2012. Unless offset by additional emissions reductions of ozone precursors, climate-driven increases in ozone will cause premature deaths, hospital visits, lost school days, and acute respiratory symptoms.

1 CLIMATE CHANGE AND HUMAN HEALTH

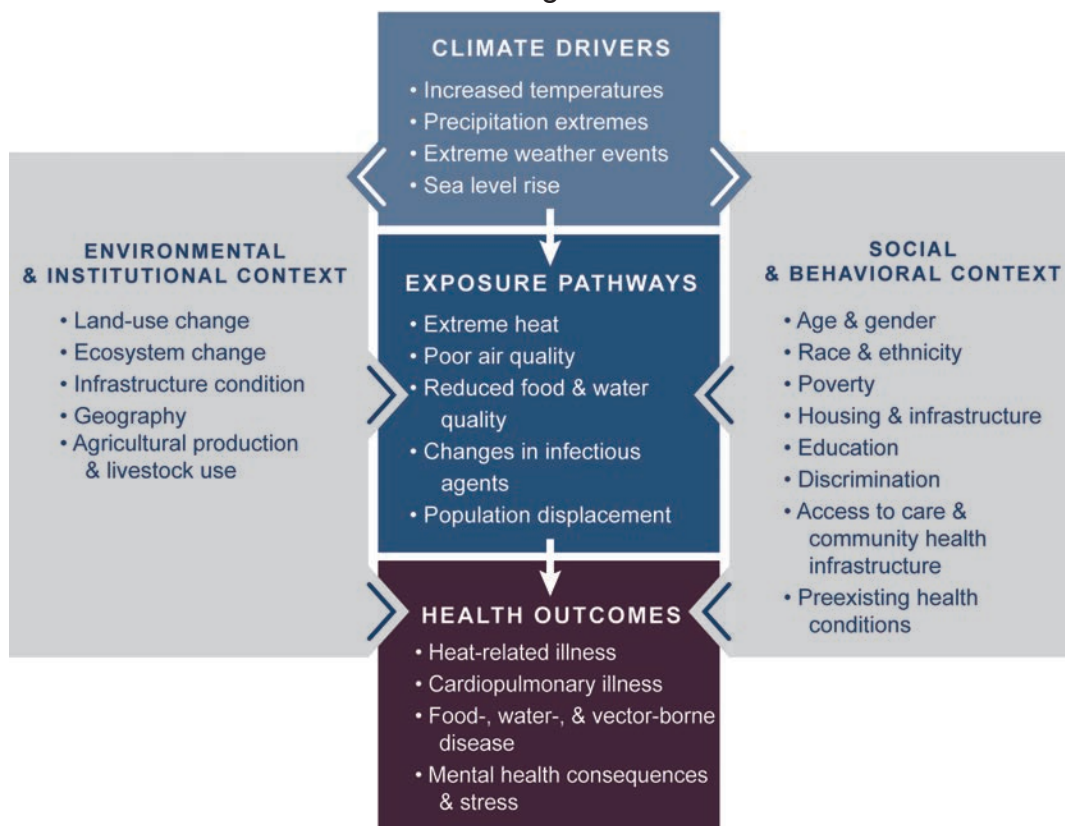
The influences of weather and climate on human health are significant and varied. Exposure to health hazards related to climate change affects different people and different communities to different degrees. While often assessed individually, exposure to multiple climate change threats can occur simultaneously, resulting in compounding or cascading health impacts.

With climate change, the frequency, severity, duration, and location of weather and climate phenomena—like rising temperatures, heavy rains and droughts, and some other kinds of severe weather—are changing. This means that areas already experiencing health-threatening weather and climate phenomena, such as severe heat or hurricanes, are likely to experience worsening impacts, such as higher temperatures and increased storm intensity, rainfall rates, and storm surge.

It also means that some locations will experience new climate-related health threats. For example, areas previously unaffected by toxic algal blooms or waterborne diseases because of cooler water temperatures may face these hazards in the future as increasing water temperatures allow the organisms that cause these health risks to thrive. Even areas that currently experience these health threats may see a shift in the timing of the seasons that pose the greatest risk to human health.








Climate change can therefore affect human health in two main ways: first, by changing the severity or frequency of health problems that are already affected by climate or weather factors; and second, by creating unprecedented or unanticipated health problems or health threats in places where they have not previously occurred.

Climate Change and Health



Conceptual diagram illustrating the exposure pathways by which climate change affects human health. Here, the center boxes list some selected examples of the kinds of changes in climate drivers, exposure, and health outcomes explored in this report. Exposure pathways exist within the context of other factors that positively or negatively influence health outcomes (gray side boxes). Some of the key factors that influence vulnerability for individuals are shown in the right box, and include social determinants of health and behavioral choices. Some key factors that influence vulnerability at larger scales, such as natural and built environments, governance and management, and institutions, are shown in the left box. All of these influencing factors can affect an individual's or a community's vulnerability through changes in exposure, sensitivity, and adaptive capacity and may also be affected by climate change.

Examples of Climate Impacts on Human Health

| | Climate Driver | Exposure | Health Outcome | Impact |
|---|---|---|--|---|
|  Extreme Heat | More frequent, severe, prolonged heat events | Elevated temperatures | Heat-related death and illness | Rising temperatures will lead to an increase in heat-related deaths and illnesses. |
|  Outdoor Air Quality | Increasing temperatures and changing precipitation patterns | Worsened air quality (ozone, particulate matter, and higher pollen counts) | Premature death, acute and chronic cardiovascular and respiratory illnesses | Rising temperatures and wildfires and decreasing precipitation will lead to increases in ozone and particulate matter, elevating the risks of cardiovascular and respiratory illnesses and death. |
|  Flooding | Rising sea level and more frequent or intense extreme precipitation, hurricanes, and storm surge events | Contaminated water, debris, and disruptions to essential infrastructure | Drowning, injuries, mental health consequences, gastrointestinal and other illness | Increased coastal and inland flooding exposes populations to a range of negative health impacts before, during, and after events. |
|  Vector-Borne Infection (Lyme Disease) | Changes in temperature extremes and seasonal weather patterns | Earlier and geographically expanded tick activity | Lyme disease | Ticks will show earlier seasonal activity and a generally northward range expansion, increasing risk of human exposure to Lyme disease-causing bacteria. |
|  Water-Related Infection (<i>Vibrio vulnificus</i>) | Rising sea surface temperature, changes in precipitation and runoff affecting coastal salinity | Recreational water or shellfish contaminated with <i>Vibrio vulnificus</i> | <i>Vibrio vulnificus</i> induced diarrhea & intestinal illness, wound and blood-stream infections, death | Increases in water temperatures will alter timing and location of <i>Vibrio vulnificus</i> growth, increasing exposure and risk of water-borne illness. |
|  Food-Related Infection (<i>Salmonella</i>) | Increases in temperature, humidity, and season length | Increased growth of pathogens, seasonal shifts in incidence of <i>Salmonella</i> exposure | <i>Salmonella</i> infection, gastrointestinal outbreaks | Rising temperatures increase <i>Salmonella</i> prevalence in food; longer seasons and warming winters increase risk of exposure and infection. |
|  Mental Health and Well-Being | Climate change impacts, especially extreme weather | Level of exposure to traumatic events, like disasters | Distress, grief, behavioral health disorders, social impacts, resilience | Changes in exposure to climate- or weather-related disasters cause or exacerbate stress and mental health consequences, with greater risk for certain populations. |

The diagram shows specific examples of how climate change can affect human health, now and in the future. These effects could occur at local, regional, or national scales. The examples listed in the first column are those described in each underlying chapter's exposure pathway diagram. Moving from left to right along one health impact row, the three middle columns show how climate drivers affect an individual's or a community's exposure to a health threat and the resulting change in health outcome. The overall climate impact is summarized in the final gray column. For a more comprehensive look at how climate change affects health, and to see the environmental, institutional, social, and behavioral factors that play an interactive role in determining health outcomes, see the exposure pathway diagrams in chapters 2–8 in the full report.

2 TEMPERATURE-RELATED DEATH AND ILLNESS

Increasing concentrations of greenhouse gases lead to an increase of both average and extreme temperatures. This is expected to lead to an increase in deaths and illness from heat and a potential decrease in deaths from cold, particularly for a number of communities especially vulnerable to these changes, such as children, the elderly, and economically disadvantaged groups.

Days that are hotter than the average seasonal temperature in the summer or colder than the average seasonal temperature in the winter cause increased levels of illness and death by compromising the body's ability to regulate its temperature or by

inducing direct or indirect health complications. Loss of internal temperature control can result in a cascade of illnesses, including heat cramps, heat exhaustion, heatstroke, and hyperthermia in the presence of extreme heat, and hypothermia and frostbite in the presence of extreme cold.

Temperature extremes can also worsen chronic conditions such as cardiovascular disease, respiratory disease, cerebrovascular disease, and diabetes-related conditions. Prolonged exposure to high temperatures is associated with increased hospital admissions for cardiovascular, kidney, and respiratory disorders.



Climate change will increase the frequency and severity of future extreme heat events while also resulting in generally warmer summers and milder winters, with implications for human health.

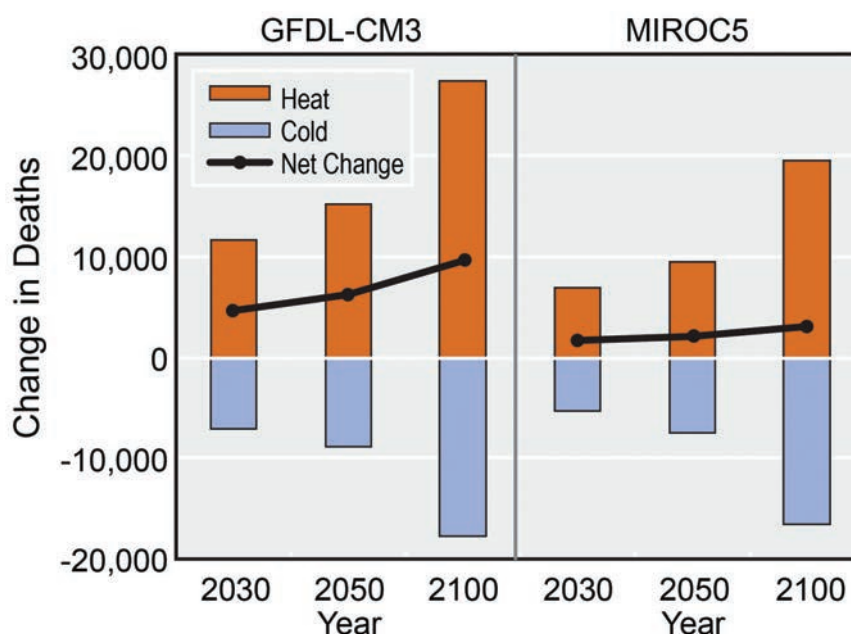
Future Increases in Temperature-Related Deaths

Key Finding 1: Based on present-day sensitivity to heat, an increase of thousands to tens of thousands of premature heat-related deaths in the summer [*Very Likely, High Confidence*] and a decrease of premature cold-related deaths in the winter [*Very Likely, Medium Confidence*] are projected each year as a result of climate change by the end of the century. Future adaptation will very likely reduce these impacts (see the Changing Tolerance to Extreme Heat Finding). The reduction in cold-related deaths is projected to be smaller than the increase in heat-related deaths in most regions [*Likely, Medium Confidence*].

Even Small Differences from Seasonal Average Temperatures Result in Illness and Death

Key Finding 2: Days that are hotter than usual in the summer or colder than usual in the winter are both associated with increased illness and death [*Very High Confidence*]. Mortality effects are observed even for small differences from seasonal average temperatures [*High Confidence*]. Because small temperature differences occur much more frequently than large temperature differences, not accounting for the effect of these small differences would lead to underestimating the future impact of climate change [*Likely, High Confidence*].

Projected Changes in Deaths in U.S. Cities by Season



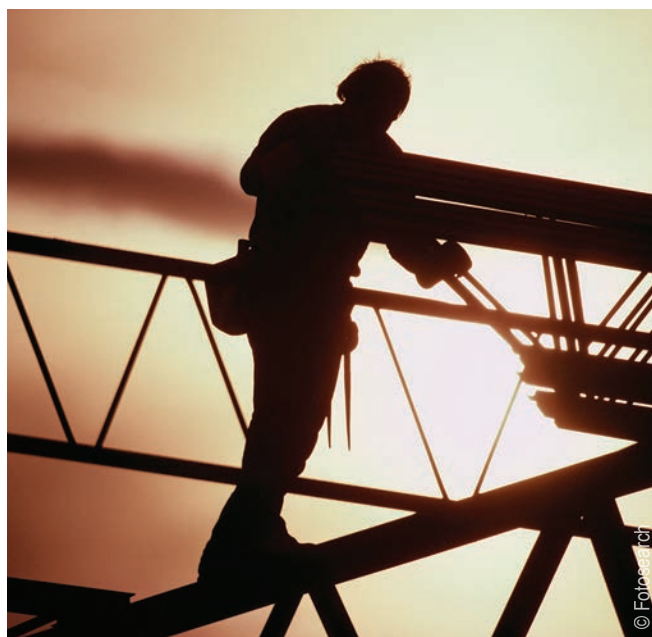
This figure shows the projected increase in deaths due to warming in the summer months (hot season, April–September), the projected decrease in deaths due to warming in the winter months (cold season, October–March), and the projected net change in deaths compared to a 1990 baseline period for the 209 U.S. cities examined, using the GFDL–CM3 and MIROC5 climate models (see Ch. 2: Temperature-Related Deaths and Illness). (Figure source: adapted from Schwartz et al. 2015)²

Changing Tolerance to Extreme Heat

Key Finding 3: An increase in population tolerance to extreme heat has been observed over time [*Very High Confidence*]. Changes in this tolerance have been associated with increased use of air conditioning, improved social responses, and/or physiological acclimatization, among other factors [*Medium Confidence*]. Expected future increases in this tolerance will reduce the projected increase in deaths from heat [*Very Likely, Very High Confidence*].

Some Populations at Greater Risk

Key Finding 4: Older adults and children have a higher risk of dying or becoming ill due to extreme heat [*Very High Confidence*]. People working outdoors, the socially isolated and economically disadvantaged, those with chronic illnesses, as well as some communities of color, are also especially vulnerable to death or illness [*Very High Confidence*].



Outdoor workers spend a great deal of time exposed to temperature extremes, often while performing vigorous activities.

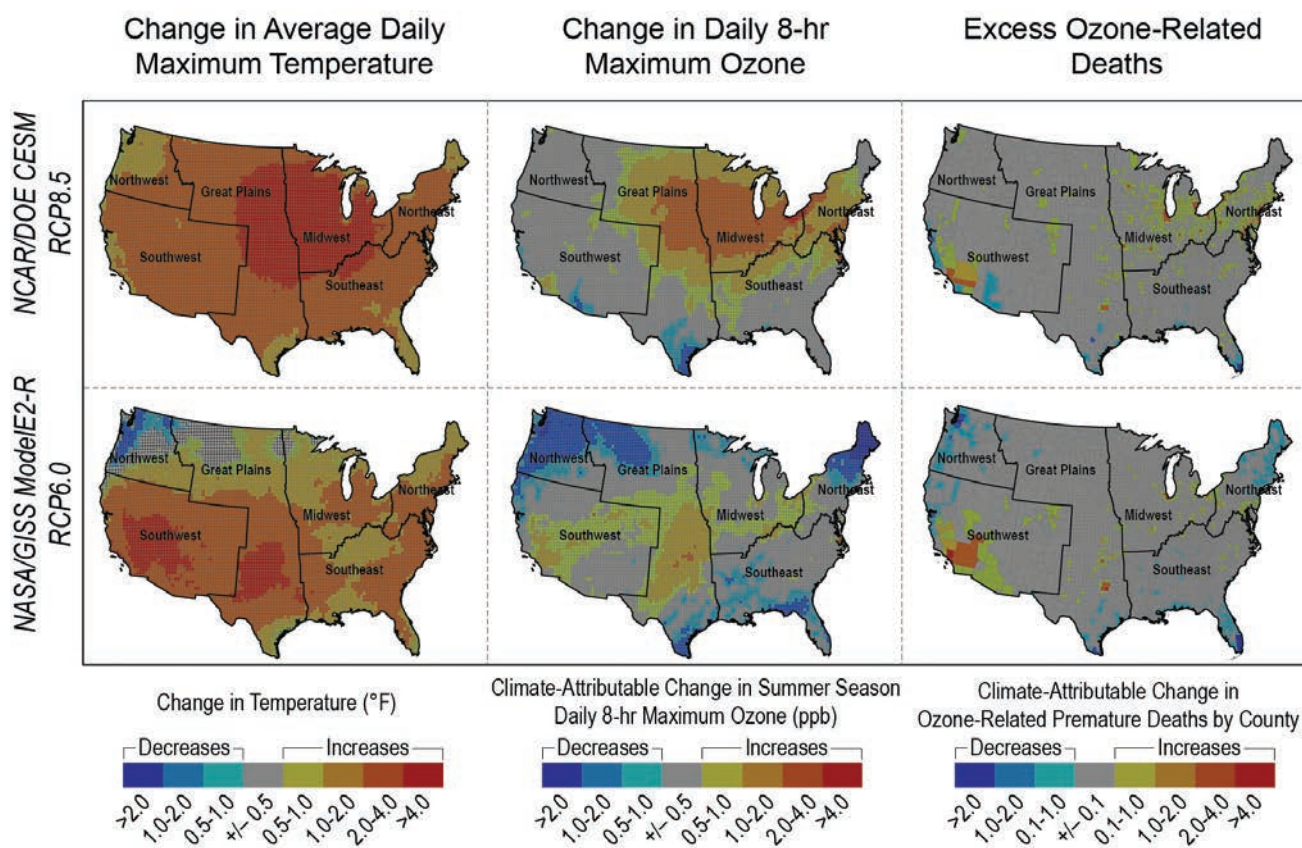
3 AIR QUALITY IMPACTS

Changes in the climate affect the air we breathe, both indoors and outdoors. The changing climate has modified weather patterns, which in turn have influenced the levels and location of outdoor air pollutants such as ground-level ozone (O_3) and fine particulate matter. Increasing carbon dioxide (CO_2) levels also promote the growth of plants that release airborne allergens (aeroallergens). Finally, these changes to outdoor air quality and aeroallergens also affect indoor air quality as both pollutants and aeroallergens infiltrate homes, schools, and other buildings. Poor air quality, whether outdoors or indoors, can negatively affect the human respiratory and cardiovascular systems. Higher pollen concentrations and longer pollen seasons can increase allergic sensitization and asthma episodes and thereby limit productivity at work and school.



Ragweed pollen frequently triggers hay fever and asthma episodes during the fall.

Projected Change in Temperature, Ozone, and Ozone-Related Premature Deaths in 2030



The air quality response to climate change can vary substantially by region across scenarios. Two downscaled global climate model projections using two greenhouse gas concentration pathways estimate increases in average daily maximum temperatures of 1.8°F to 7.2°F (1°C to 4°C) and increases of 1 to 5 parts per billion (ppb) in daily 8-hour maximum ozone in the year 2030 relative to the year 2000 throughout the continental United States. Unless reductions in ozone precursor emissions offset the influence of climate change, this “climate penalty” of increased ozone concentrations due to climate change would result in tens to thousands of additional ozone-related premature deaths per year, shown here as incidences per year by county (see Ch. 3: Air Quality Impacts). (Figure source: adapted from Fann et al. 2015)³

Exacerbated Ozone Health Impacts

Key Finding 1: Climate change will make it harder for any given regulatory approach to reduce ground-level ozone pollution in the future as meteorological conditions become increasingly conducive to forming ozone over most of the United States [*Likely, High Confidence*]. Unless offset by additional emissions reductions of ozone precursors, these climate-driven increases in ozone will cause premature deaths, hospital visits, lost school days, and acute respiratory symptoms [*Likely, High Confidence*].

Increased Health Impacts from Wildfires

Key Finding 2: Wildfires emit fine particles and ozone precursors that in turn increase the risk of premature death and adverse chronic and acute cardiovascular and respiratory health outcomes [*Likely, High Confidence*]. Climate change is projected to increase the number and severity of naturally occurring wildfires in parts of the United States, increasing emissions of particulate matter and ozone precursors and resulting in additional adverse health outcomes [*Likely, High Confidence*].

Worsened Allergy and Asthma Conditions

Key Finding 3: Changes in climate, specifically rising temperatures, altered precipitation patterns, and increasing concentrations of atmospheric carbon dioxide, are expected to contribute to increases in the levels of some airborne allergens and associated increases in asthma episodes and other allergic illnesses [*High Confidence*].



Courtesy of Bart Everson/flickr



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(Top) Dampness and mold in U.S. homes are linked to approximately 4.6 million cases of worsened asthma. (Left) Wildfires are a major source of airborne particulate matter, especially in the western United States during summer. Climate change has already led to an increased frequency of large wildfires, as well as longer durations of individual wildfires and longer wildfire seasons in the western United States. (Right) Nearly 6.8 million children in the United States are affected by asthma, making it a major chronic disease of childhood.

4 IMPACTS OF EXTREME EVENTS ON HUMAN HEALTH

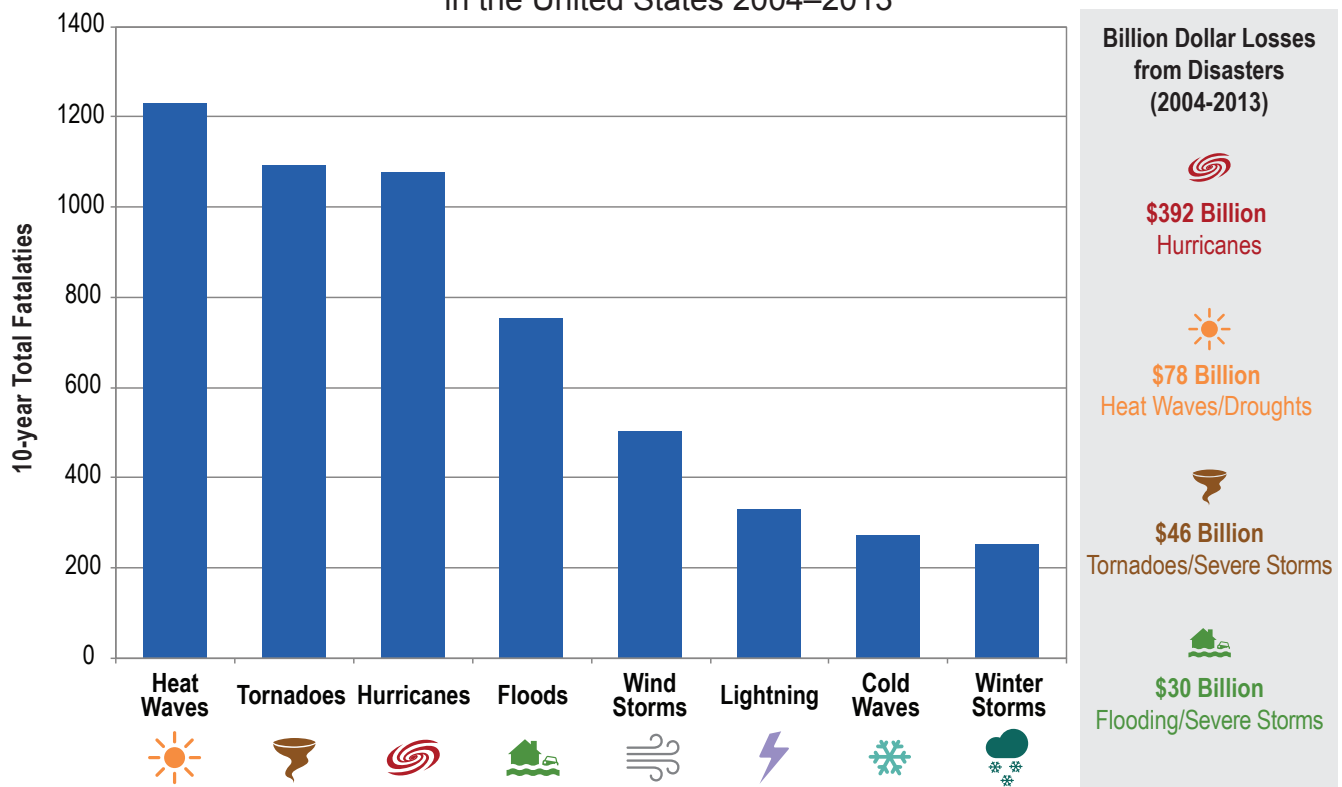
Climate change projections show that there will be continuing increases in the occurrence and severity of some extreme events by the end of the century, while for other extremes the links to climate change are more uncertain. Some regions of the United States have already experienced costly impacts—in terms of both lives lost and economic damages—from observed changes in the frequency, intensity, or duration of certain extreme events.

While it is intuitive that extremes can have health impacts such as death or injury during an event (for example, drowning during floods), health impacts can also occur before or after an extreme event, as individuals may be involved in activities that put their health at risk, such as disaster

preparation and post-event cleanup. Health risks may also arise long after the event, or in places outside the area where the event took place, as a result of damage to property, destruction of assets, loss of infrastructure and public services, social and economic impacts, environmental degradation, and other factors.

Extreme events also pose unique health risks if multiple events occur simultaneously or in succession in a given location. The severity and extent of health effects associated with extreme events depend on the physical impacts of the extreme events themselves as well as the unique human, societal, and environmental circumstances at the time and place where events occur.

Estimated Deaths and Billion Dollar Losses from Extreme Events in the United States 2004–2013



This figure provides 10-year estimates of fatalities related to extreme events from 2004 to 2013,⁴ as well as estimated economic damages from 58 weather and climate disaster events with losses exceeding \$1 billion (see Smith and Katz 2013 to understand how total losses were calculated).⁵ These statistics are indicative of the human and economic costs of extreme weather events over this time period. Climate change will alter the frequency, intensity, and geographic distribution of some of these extremes,¹ which has consequences for exposure to health risks from extreme events. Trends and future projections for some extremes, including tornadoes, lightning, and wind storms are still uncertain (see Ch. 4: Extreme Events).

Increased Exposure to Extreme Events

Key Finding 1: Health impacts associated with climate-related changes in exposure to extreme events include death, injury, or illness; exacerbation of underlying medical conditions; and adverse effects on mental health [*High Confidence*]. Climate change will increase exposure risk in some regions of the United States due to projected increases in the frequency and/or intensity of drought, wildfires, and flooding related to extreme precipitation and hurricanes [*Medium Confidence*].



(Top) A truck gets stuck in the storm surge covering Highway 90 in Gulfport, Mississippi, during Hurricane Isaac. (Bottom) Power lines damaged in Plaquemines Parish, Louisiana, by Hurricane Isaac. September 3, 2012.



Family farmer in drought-stressed peanut field, Unadilla, Georgia. July 24, 2012.

Disruption of Essential Infrastructure

Key Finding 2: Many types of extreme events related to climate change cause disruption of infrastructure, including power, water, transportation, and communication systems, that are essential to maintaining access to health care and emergency response services and safeguarding human health [*High Confidence*].

Vulnerability to Coastal Flooding

Key Finding 3: Coastal populations with greater vulnerability to health impacts from coastal flooding include persons with disabilities or other access and functional needs, certain populations of color, older adults, pregnant women and children, low-income populations, and some occupational groups [*High Confidence*]. Climate change will increase exposure risk to coastal flooding due to increases in extreme precipitation and in hurricane intensity and rainfall rates, as well as sea level rise and the resulting increases in storm surge [*High Confidence*].

5 VECTOR-BORNE DISEASES

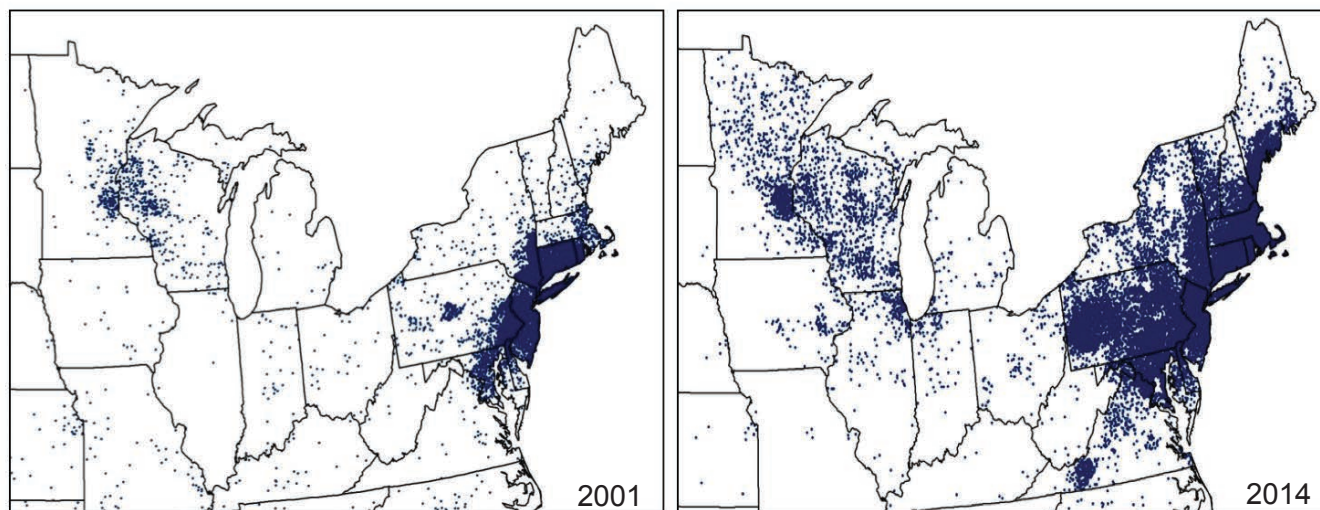
Vector-borne diseases are illnesses that are transmitted by vectors, which include mosquitoes, ticks, and fleas. These vectors can carry infective pathogens such as viruses, bacteria, and protozoa, which can be transferred from one host (carrier) to another. The seasonality, distribution, and prevalence of vector-borne diseases are influenced significantly by climate factors, primarily high and low temperature extremes and precipitation patterns.

Climate change is likely to have both short- and long-term effects on vector-borne disease transmission and infection patterns, affecting both seasonal risk and broad geographic changes in disease occurrence over decades. While climate variability and climate change both alter the transmission of vector-borne diseases, they will likely interact with many other factors, including how pathogens adapt and change, the availability of hosts, changing ecosystems and land use, demographics, human behavior, and adaptive capacity. These complex interactions make it difficult to predict the effects of climate change on vector-borne diseases.



In the eastern United States, Lyme disease is transmitted to humans primarily by blacklegged (deer) ticks.

Changes in Lyme Disease Case Report Distribution



Maps show the reported cases of Lyme disease in 2001 and 2014 for the areas of the country where Lyme disease is most common (the Northeast and Upper Midwest). Both the distribution and the numbers of cases have increased (see Ch. 5: Vector-Borne Diseases). (Figure source: adapted from CDC 2015)⁶

Changing Distributions of Vectors and Vector-Borne Diseases

Key Finding 1: Climate change is expected to alter the geographic and seasonal distributions of existing vectors and vector-borne diseases [*Likely, High Confidence*].

Earlier Tick Activity and Northward Range Expansion

Key Finding 2: Ticks capable of carrying the bacteria that cause Lyme disease and other pathogens will show earlier seasonal activity and a generally northward expansion in response to increasing temperatures associated with climate change [*Likely, High Confidence*]. Longer seasonal activity and expanding geographic range of these ticks will increase the risk of human exposure to ticks [*Likely, Medium Confidence*].

Changing Mosquito-Borne Disease Dynamics

Key Finding 3: Rising temperatures, changing precipitation patterns, and a higher frequency of some extreme weather events associated with climate change will influence the distribution, abundance, and prevalence of infection in the mosquitoes that transmit West Nile virus and other pathogens by altering habitat availability and mosquito and viral reproduction rates [*Very Likely, High Confidence*]. Alterations in the distribution, abundance, and infection rate of mosquitoes will influence human exposure to bites from infected mosquitoes, which is expected to alter risk for human disease [*Very Likely, Medium Confidence*].

Emergence of New Vector-Borne Pathogens

Key Finding 4: Vector-borne pathogens are expected to emerge or reemerge due to the interactions of climate factors with many other drivers, such as changing land-use patterns [*Likely, High Confidence*]. The impacts to human disease, however, will be limited by the adaptive capacity of human populations, such as vector control practices or personal protective measures [*Likely, High Confidence*].



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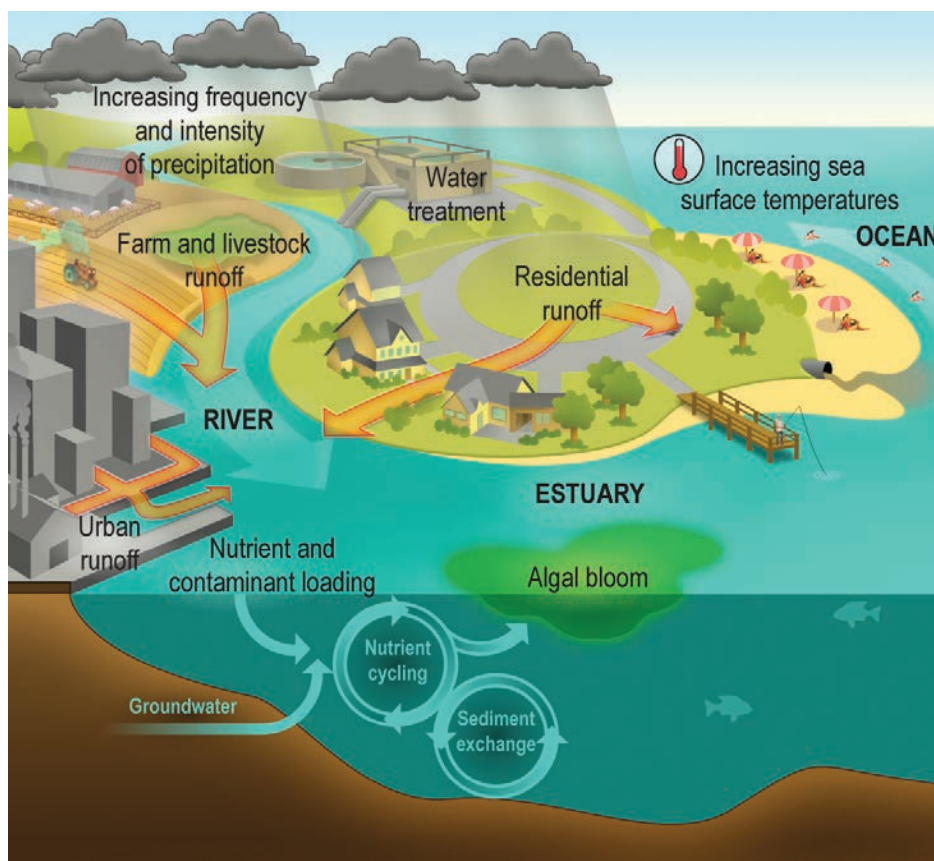
Birds such as the house finch are the natural host of West Nile virus. Humans can be infected from a bite of a mosquito that has previously bitten an infected bird.

6 CLIMATE IMPACTS ON WATER-RELATED ILLNESSES

Across most of the United States, climate change is expected to affect fresh and marine water resources in ways that will increase people's exposure to water-related contaminants that cause illness. Water-related illnesses include waterborne diseases caused by pathogens, such as bacteria, viruses, and protozoa. Water-related illnesses are also caused by toxins produced by certain harmful algae and cyanobacteria and by chemicals introduced into the environment by human activities. Exposure occurs through ingestion, inhalation, or direct contact with contaminated drinking or recreational water and through consumption of contaminated fish and shellfish. Factors related to climate change—including temperature, precipitation and related runoff,

hurricanes, and storm surge—affect the growth, survival, spread, and virulence or toxicity of agents (causes) of water-related illness. Whether or not illness results from exposure to contaminated water, fish, or shellfish is dependent on a complex set of factors, including human behavior and social determinants of health that may affect a person's exposure, sensitivity, and adaptive capacity. Water resource, public health, and environmental agencies in the United States provide many public health safeguards to reduce risk of exposure and illness even if water becomes contaminated. These include water quality monitoring, drinking water treatment standards and practices, beach closures, and issuing advisories for boiling drinking water and harvesting shellfish.

Links between Climate Change, Water Quantity and Quality, and Human Exposure to Water-Related Illness



Precipitation and temperature changes affect fresh and marine water quantity and quality primarily through urban, rural, and agriculture runoff. This runoff in turn affects human exposure to water-related illnesses primarily through contamination of drinking water, recreational water, and fish or shellfish (see Ch. 6: Water-Related Illness).



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Red tide bloom, Hood Canal, Puget Sound, Washington State.

Seasonal and Geographic Changes in Waterborne Illness Risk

Key Finding 1: Increases in water temperatures associated with climate change will alter the seasonal windows of growth and the geographic range of suitable habitat for freshwater toxin-producing harmful algae [*Very Likely, High Confidence*], certain naturally occurring *Vibrio* bacteria [*Very Likely, Medium Confidence*], and marine toxin-producing harmful algae [*Likely, Medium Confidence*]. These changes will increase the risk of exposure to waterborne pathogens and algal toxins that can cause a variety of illnesses [*Medium Confidence*].

Runoff from Extreme Precipitation Increases Exposure Risk

Key Finding 2: Runoff from more frequent and intense extreme precipitation events will increasingly compromise recreational waters, shellfish harvesting waters, and sources of drinking water through increased introduction of pathogens and prevalence of toxic algal blooms [*High Confidence*]. As a result, the risk of human exposure to agents of water-related illness will increase [*Medium Confidence*].

Water Infrastructure Failure

Key Finding 3: Increases in some extreme weather events and storm surges will increase the risk that infrastructure for drinking water, wastewater, and stormwater will fail due to either damage or exceedance of system capacity, especially in areas with aging infrastructure [*High Confidence*]. As a result, the risk of exposure to water-related pathogens, chemicals, and algal toxins will increase in recreational and shellfish harvesting waters, and in drinking water where treatment barriers break down [*Medium Confidence*].



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Young women walk through floodwater in the historic district of Charleston, South Carolina, as Hurricane Joaquin passes offshore. October 4, 2015.

7 FOOD SAFETY, NUTRITION, AND DISTRIBUTION

A safe and nutritious food supply is a vital component of food security. The impacts of climate change on food production, prices, and trade for the United States and globally have been widely examined, including in the recent report “Climate Change, Global Food Security, and the U.S. Food System.”⁷ An overall finding of that report was that “climate change is very likely to affect global, regional, and local food security by disrupting food availability, decreasing access to food, and making utilization more difficult.”

This chapter focuses on some of the less reported aspects of food security, specifically the impacts of climate change on food safety, nutrition, and distribution. There are two overarching means by

which increasing carbon dioxide (CO₂) and climate change alter safety, nutrition, and distribution of food. The first is associated with rising global temperatures and the subsequent changes in weather patterns and extreme climate events. Current and anticipated changes in climate and the physical environment have consequences for contamination, spoilage, and the disruption of food distribution. The second pathway is through the direct CO₂ “fertilization” effect on plant photosynthesis. Higher concentrations of CO₂ stimulate growth and carbohydrate production in some plants, but can lower the levels of protein and essential minerals in a number of widely consumed crops, including wheat, rice, and potatoes, with potentially negative implications for human nutrition.

Farm to Table

The Potential Interactions of Rising CO₂ and Climate Change on Food Safety



The food system involves a network of interactions with our physical and biological environments as food moves from production to consumption, or from “farm to table.” Rising CO₂ and climate change will affect the quality and distribution of food, with subsequent effects on food safety and nutrition (see Ch. 7: Food Safety).

Increased Risk of Foodborne Illness

Key Finding 1: Climate change, including rising temperatures and changes in weather extremes, is expected to increase the exposure of food to certain pathogens and toxins *[Likely, High Confidence]*. This will increase the risk of negative health impacts *[Likely, Medium Confidence]*, but actual incidence of foodborne illness will depend on the efficacy of practices that safeguard food in the United States *[High Confidence]*.

Chemical Contaminants in the Food Chain

Key Finding 2: Climate change will increase human exposure to chemical contaminants in food through several pathways *[Likely, Medium Confidence]*. Elevated sea surface temperatures will lead to greater accumulation of mercury in seafood *[Likely, Medium Confidence]*, while increases in extreme weather events will introduce contaminants into the food chain *[Likely, Medium Confidence]*. Rising carbon dioxide concentrations and climate change will alter incidence and distribution of pests, parasites, and microbes *[Very Likely, High Confidence]*, leading to increases in the use of pesticides and veterinary drugs *[Likely, Medium Confidence]*.

Rising Carbon Dioxide Lowers Nutritional Value of Food

Key Finding 3: The nutritional value of agriculturally important food crops, such as wheat and rice, will decrease as rising levels of atmospheric carbon dioxide continue to reduce the concentrations of protein and essential minerals in most plant species *[Very Likely, High Confidence]*.

Extreme Weather Limits Access to Safe Foods

Key Finding 4: Increases in the frequency or intensity of some extreme weather events associated with climate change will increase disruptions of food distribution by damaging existing infrastructure or slowing food shipments *[Likely, High Confidence]*. These impediments lead to increased risk for food damage, spoilage, or contamination, which will limit availability of and access to safe and nutritious food depending on the extent of disruption and the resilience of food distribution infrastructure *[Medium Confidence]*.



(Left) The risk of foodborne illness is higher when food is prepared outdoors. (Right) Crop dusting of a corn field in Iowa.

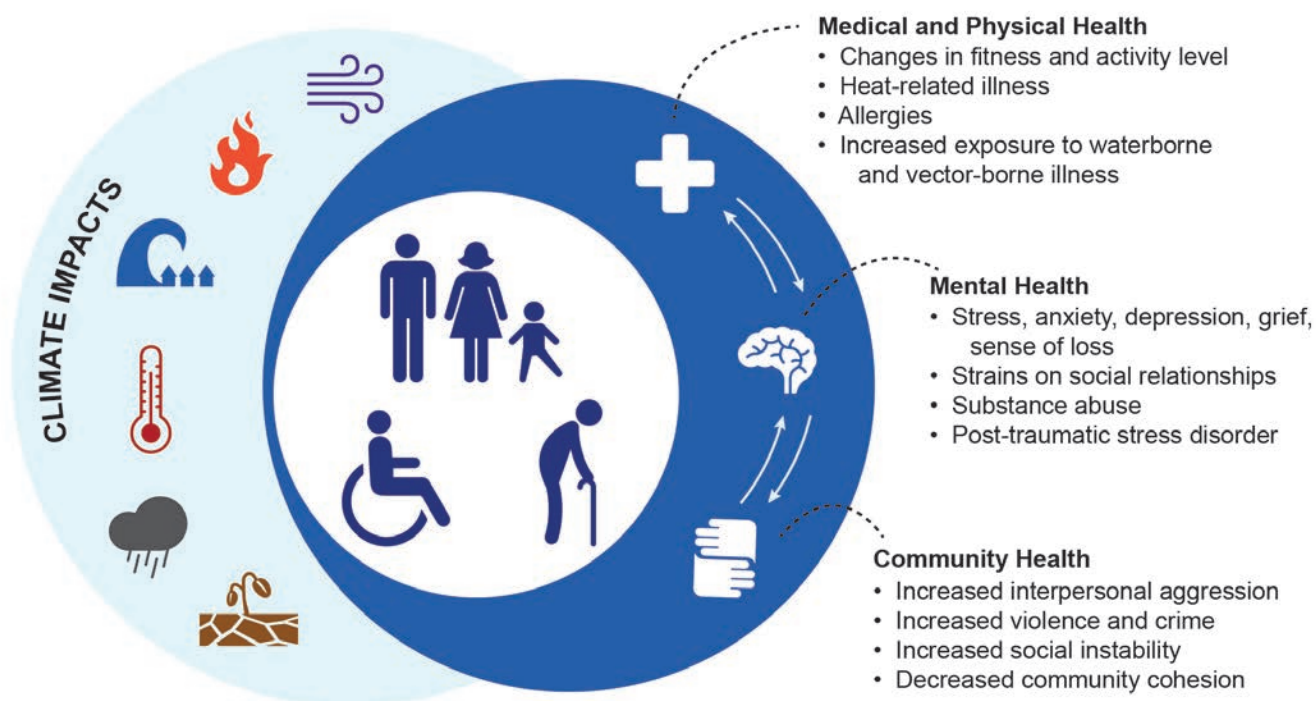
8 MENTAL HEALTH AND WELL-BEING

The effects of global climate change on mental health and well-being are integral parts of the overall climate-related human health impacts. Mental health consequences of climate change range from minimal stress and distress symptoms to clinical disorders, such as anxiety, depression, post-traumatic stress, and suicidality. Other consequences include effects on the everyday life, perceptions, and experiences of individuals and communities attempting to understand and respond appropriately to climate change and its implications. The mental health and well-being consequences of climate change related impacts rarely occur in isolation, but often interact with other social and environmental stressors. The interactive and cumulative nature of climate change effects on health, mental health, and well-being are critical factors in understanding the overall consequences of climate change on human health.



Children are at particular risk for distress, anxiety, and other adverse mental health effects in the aftermath of an extreme event.

The Impact of Climate Change on Physical, Mental, and Community Health



At the center of the diagram are human figures representing adults, children, older adults, and people with disabilities. The left circle depicts climate impacts including air quality, wildfire, sea level rise and storm surge, heat, storms, and drought. The right circle shows the three interconnected health domains that will be affected by climate impacts: Medical and Physical Health, Mental Health, and Community Health (see Ch. 8: Mental Health). (Figure source: adapted from Clayton et al. 2014)⁷

Exposure to Disasters Results in Mental Health Consequences

Key Finding 1: Many people exposed to climate-related or weather-related disasters experience stress and serious mental health consequences. Depending on the type of the disaster, these consequences include post-traumatic stress disorder (PTSD), depression, and general anxiety, which often occur at the same time *[Very High Confidence]*. The majority of affected people recover over time, although a significant proportion of exposed individuals develop chronic psychological dysfunction *[High Confidence]*.

Specific Groups of People Are at Higher Risk

Key Finding 2: Specific groups of people are at higher risk for distress and other adverse mental health consequences from exposure to climate-related or weather-related disasters. These groups include children, the elderly, women (especially pregnant and post-partum women), people with preexisting mental illness, the economically disadvantaged, the homeless, and first responders *[High Confidence]*. Communities that rely on the natural environment for sustenance and livelihood, as well as populations living in areas most susceptible to specific climate change events, are at increased risk for adverse mental health outcomes *[High Confidence]*.



Residents and volunteers in the Rockaways section of Queens in New York City filter through clothes and food supplies from donors following Superstorm Sandy. November 3, 2012.



© U.S. Air Force/Staff Sgt. James L. Harper Jr.



Courtesy of flickr/fish.pro

(Top) Rescue worker receives hug from Galveston, TX, resident after Hurricane Ike, September 2008. (Bottom) People experience the threat of climate change through frequent media coverage.

Climate Change Threats Result in Mental Health Consequences and Social Impacts

Key Finding 3: Many people will experience adverse mental health outcomes and social impacts from the threat of climate change, the perceived direct experience of climate change, and changes to one's local environment *[High Confidence]*. Media and popular culture representations of climate change influence stress responses and mental health and well-being *[Medium Confidence]*.

Extreme Heat Increases Risks for People with Mental Illness

Key Finding 4: People with mental illness are at higher risk for poor physical and mental health due to extreme heat *[High Confidence]*. Increases in extreme heat will increase the risk of disease and death for people with mental illness, including elderly populations and those taking prescription medications that impair the body's ability to regulate temperature *[High Confidence]*.

9 POPULATIONS OF CONCERN

Climate change is already causing, and is expected to continue to cause, a range of health impacts that vary across different population groups in the United States. The vulnerability of any given group is a function of its sensitivity to climate change related health risks, its exposure to those risks, and its capacity for responding to or coping with climate variability and change. Vulnerable groups of people, described here as populations of concern, include those with low income, some

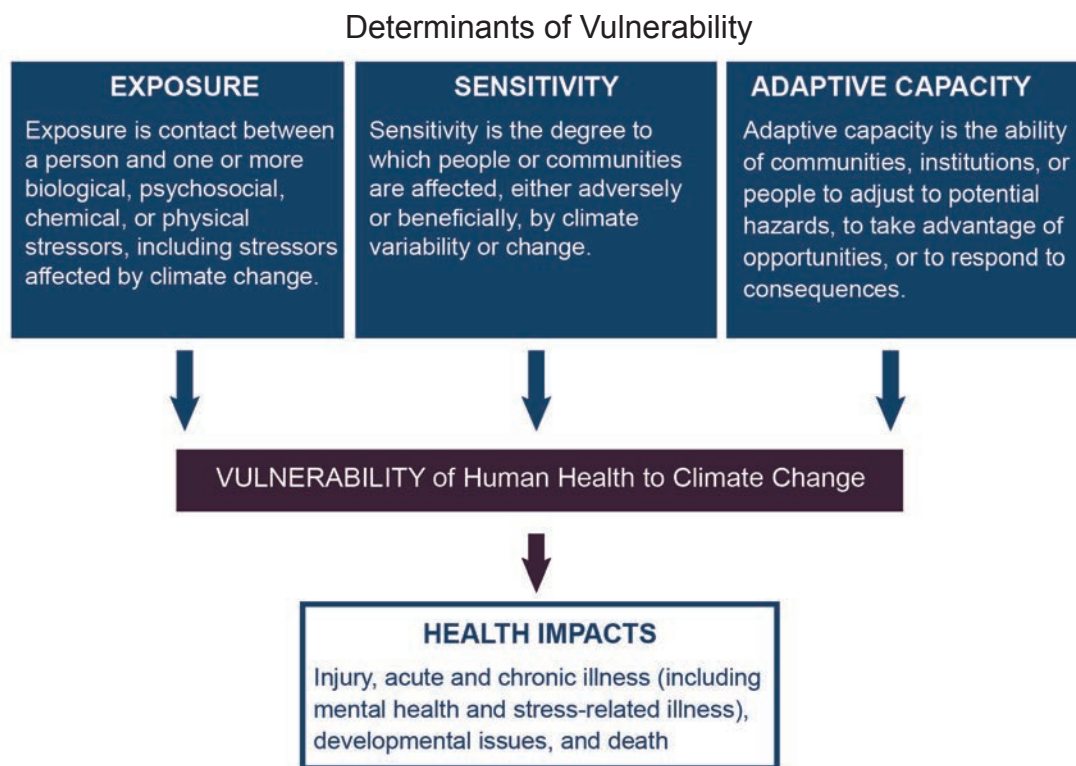
communities of color, immigrant groups (including those with limited English proficiency), Indigenous peoples, children and pregnant women, older adults, vulnerable occupational groups, persons with disabilities, and persons with preexisting or chronic medical conditions. Characterizations of vulnerability should consider how populations of concern experience disproportionate, multiple, and complex risks to their health and well-being in response to climate change.

Vulnerability Varies Over Time and Is Place-Specific

Key Finding 1: Across the United States, people and communities differ in their exposure, their inherent sensitivity, and their adaptive capacity to respond to and cope with climate change related health threats [*Very High Confidence*]. Vulnerability to climate change varies across time and location, across communities, and among individuals within communities [*Very High Confidence*].

Health Impacts Vary with Age and Life Stage

Key Finding 2: People experience different inherent sensitivities to the impacts of climate change at different ages and life stages [*High Confidence*]. For example, the very young and the very old are particularly sensitive to climate-related health impacts.



Defining the determinants of vulnerability to health impacts associated with climate change, including exposure, sensitivity, and adaptive capacity (see Ch. 9: Populations of Concern). (Figure source: adapted from Turner et al. 2003)⁸



Social Determinants of Health Interact with Climate Factors to Affect Health Risk

Key Finding 3: Climate change threatens the health of people and communities by affecting exposure, sensitivity, and adaptive capacity *[High Confidence]*. Social determinants of health, such as those related to socioeconomic factors and health disparities, may amplify, moderate, or otherwise influence climate-related health effects, particularly when these factors occur simultaneously or close in time or space *[High Confidence]*.

Mapping Tools and Vulnerability Indices Identify Climate Health Risks

Key Finding 4: The use of geographic data and tools allows for more sophisticated mapping of risk factors and social vulnerabilities to identify and protect specific locations and groups of people *[High Confidence]*.



(Left) Persons with disabilities often rely on medical equipment (such as portable oxygen) that requires an uninterrupted source of electricity. (Right) Climate-related exposures may lead to adverse pregnancy and newborn health outcomes.



Because of existing vulnerabilities, Indigenous people, especially those who are dependent on the environment for sustenance or who live in geographically isolated or impoverished communities, are likely to experience greater exposure and lower resilience to climate-related health effects.

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