



9 POPULATIONS OF CONCERN

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9 POPULATIONS OF CONCERN



Key Findings

Vulnerability Varies Over Time and Is Place-Specific

Key Finding 1: Across the United States, people and communities differ in their exposures, 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.

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

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]*.

9.1 Introduction

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. Planners and public health officials, politicians and physicians, scientists and social service providers are tasked with understanding and responding to the health impacts of climate change. Collectively, their characterization 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.

Some groups face a number of stressors related to both climate and non-climate factors. For example, people living in impoverished urban or isolated rural areas, floodplains, coastlines, and other at-risk locations are more vulnerable not only to extreme weather and persistent climate change but also to social and economic stressors. Many of these stressors can occur simultaneously or consecutively. Over time, this “accumulation” of multiple, complex stressors is expected to become more evident¹ as climate impacts interact with stressors associated with existing mental and physical health conditions and with other socioeconomic and demographic factors.

9.2 A Framework for Understanding Vulnerability

Some populations of concern demonstrate relatively greater vulnerability to the health impacts of climate change. The definitions of the following key concepts are important to understand how some people or communities are disproportionately affected by climate-related health risks (Figure 1). Definitions are adapted from the Intergovernmental Panel on Climate Change (IPCC) and the National Research Council (NRC).^{2,3}

- **Vulnerability** is the tendency or predisposition to be adversely affected by climate-related health effects, and encompasses three elements: exposure, sensitivity or susceptibility to harm, and the capacity to adapt to or to cope with change. *Exposure* is contact between a person and one or more biological, chemical, or physical stressors, including stressors affected by climate change. Contact may occur in a single instance or repeatedly over time, and may occur in one location or over a wider geographic area. *Sensitivity* is the degree to which people or communities are affected,



Food is distributed to people in need at Catholic Community Service in Wheaton, MD, November 23, 2010. Populations of concern experience disproportionate, multiple, and complex risks to their health and well-being in response to climate change.

either adversely or beneficially, by climate variability and change. *Adaptive capacity* is the ability of communities, institutions, or people to adjust to potential hazards, to take advantage of opportunities, or to respond to consequences. A related term, *resilience*, is the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events. People and communities with strong adaptive capacity have greater resilience.

- **Risk** is the potential for consequences to develop where something of value (such as human health) is at stake and where the outcome is uncertain. Risk is often represented as the probability of the occurrence of a hazardous event multiplied by the expected severity of the impacts of that event.
- **Stressors** are events or trends, whether related to climate change or other factors, that increase vulnerability to health effects.

People or communities can have greater or lesser vulnerability to health risks depending on social, political, and economic factors that are collectively known as social determinants of health.⁵ Some groups are disproportionately disadvantaged by social determinants of health that limit resources and opportunities for health-promoting behaviors and conditions of daily life, such as living/working circumstances and access to healthcare services.⁵ In disadvantaged groups, social determinants of health interact with the three elements of vulnerability by contributing to increased exposure, increased sensitivity, and reduced adaptive capacity (Figure 2). Health risks and vulnerability may increase in locations or instances where combinations of social determinants of health that amplify health threats occur simultaneously or close in time or space.^{6,7} For example, people with limited economic resources living in areas with deteriorating infrastructure are more likely to experience disproportionate impacts and are less

Determinants of Vulnerability

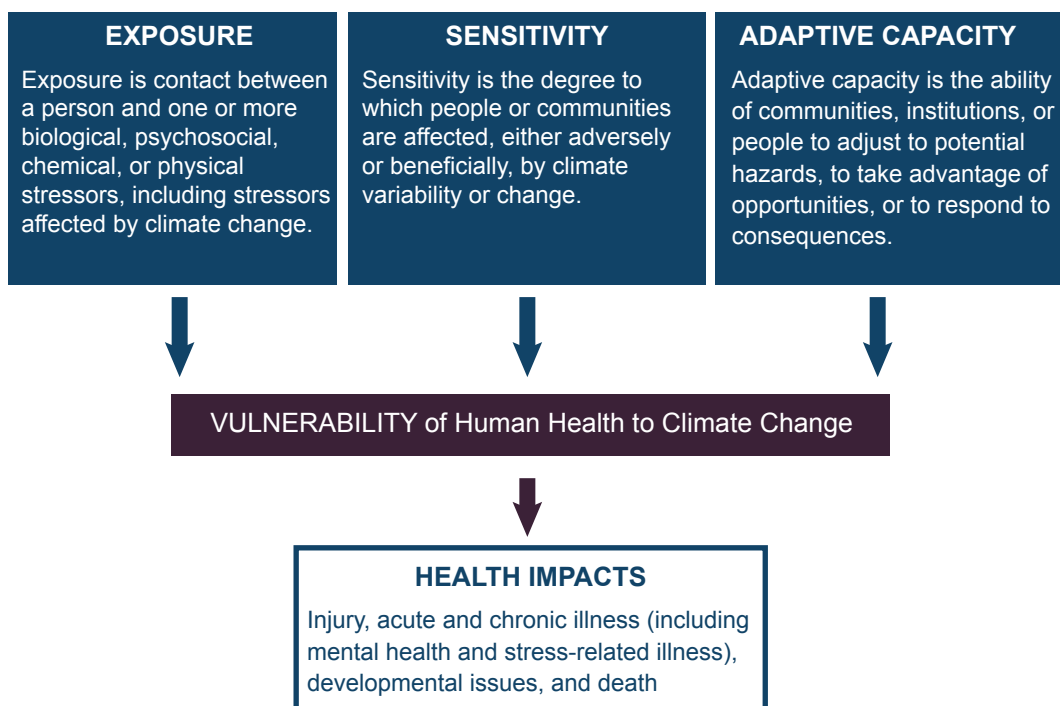


Figure 1: Defining the determinants of vulnerability to health impacts associated with climate change, including exposure, sensitivity, and adaptive capacity. (Figure source: adapted from Turner et al. 2003)⁴

able to recover following extreme events,^{8,9} increasing their vulnerability to climate-related health effects. Understanding the role of social determinants of health can help characterize climate change impacts and identify public health interventions or actions to reduce or prevent exposures in populations of concern.^{6,7,10}

Factors that Contribute to Exposure

Exposures to climate-related variability and change are determined by a range of factors that individually and collectively shape the nature and extent of exposures. These factors include:

- **Occupation:** Certain occupations have a greater risk of exposure to climate impacts. People working outdoors or performing duties that expose them to extreme weather, such as emergency responders, utility repair crews, farm workers, construction workers, and other outdoor laborers, are at particular risk.¹¹
- **Time spent in risk-prone locations:** Where a person lives, goes to school, works, or spends leisure time will contribute to exposure. Locations with greater health threats include urban areas (due to, for example, the “heat island” effect or air quality concerns), areas where airborne allergens and other air pollutants occur at levels that aggravate respiratory illnesses, communities experiencing depleted water supplies or vulnerable energy and transportation infrastructure, coastal and other flood-prone areas, and locations affected

by drought and wildfire.^{12,13,14}

- **Responses to extreme events:** A person’s ability or, in some cases, their choice whether to evacuate or shelter-in-place in response to an extreme event such as a hurricane, flood, or wildfire affects their exposure to health threats. Low-income populations are generally less likely to evacuate in response to a warning (see Ch. 4: Extreme Events).⁸
- **Socioeconomic status:** Persons living in poverty are more likely to be exposed to extreme heat and air pollution.^{15,16} Poverty also determines, at least in part, how people perceive the risks to which they are exposed, how they respond to evacuation orders and other emergency warnings, and their ability to evacuate or relocate to a less risk-prone location (see Ch. 8: Mental Health).⁸
- **Infrastructure condition and access:** Older buildings may expose occupants to increased indoor air pollutants and mold, stagnant airflow, or high indoor temperatures (see Ch. 3: Air Quality Impacts). Persons preparing for or responding to flooding, wildfires, or other weather-related emergencies may be hampered by disruption to transportation, utilities, medical, or communication infrastructure. Lack of access to these resources, in either urban or rural settings, can increase a person’s vulnerability (see Ch. 4: Extreme Events).^{17,18}

- Compromised mobility, cognitive function, and other mental or behavioral factors:** These factors can lead to increased exposure to climate-related health impacts if people are not aware of health threats or are unable to take actions to avoid, limit, or respond to risks.¹⁹ People with access and functional needs may be particularly at risk if these factors interfere with their ability to access or receive medical care before, during, or after a disaster or emergency.

Characterizing Biological Sensitivity

The sensitivity of human communities and individuals to climate change stressors is determined, at least in part, by biological traits. Among those traits are the overall health status, age, and life stage. From fetus, to infant, to toddler, to child, to adolescent, to adult, to the elderly, persons at every life stage have varying sensitivity to climate change impacts.^{12, 20, 21} For instance, the relatively immature immune systems of very young children make them more sensitive to aeroallergen exposure (such as airborne pollens). In addition to life stage,

people experiencing long-term chronic medical and/or psychological conditions are more sensitive to climate stressors. Persons with asthma or chronic obstructive pulmonary disease (COPD) are more sensitive to exposures to wildfire smoke and other respiratory irritants. Social and economic factors also affect disparities in the prevalence of chronic medical conditions that aggravate biological sensitivity.^{22, 23}

Adaptive Capacity and Response to Climate Change

Many of the same factors that contribute to exposure or sensitivity also influence the ability of both individuals and communities to adapt to climate variability and change. Socioeconomic status, the condition and accessibility of infrastructure, the accessibility of health care, certain demographic characteristics, human and social capital (the skills, knowledge, experience, and social cohesion of a community), and other institutional resources all contribute to the timeliness and effectiveness of adaptive capacity (see Ch. 1: Introduction and Ch. 4: Extreme Events).

Intersection of Social Determinants of Health and Vulnerability

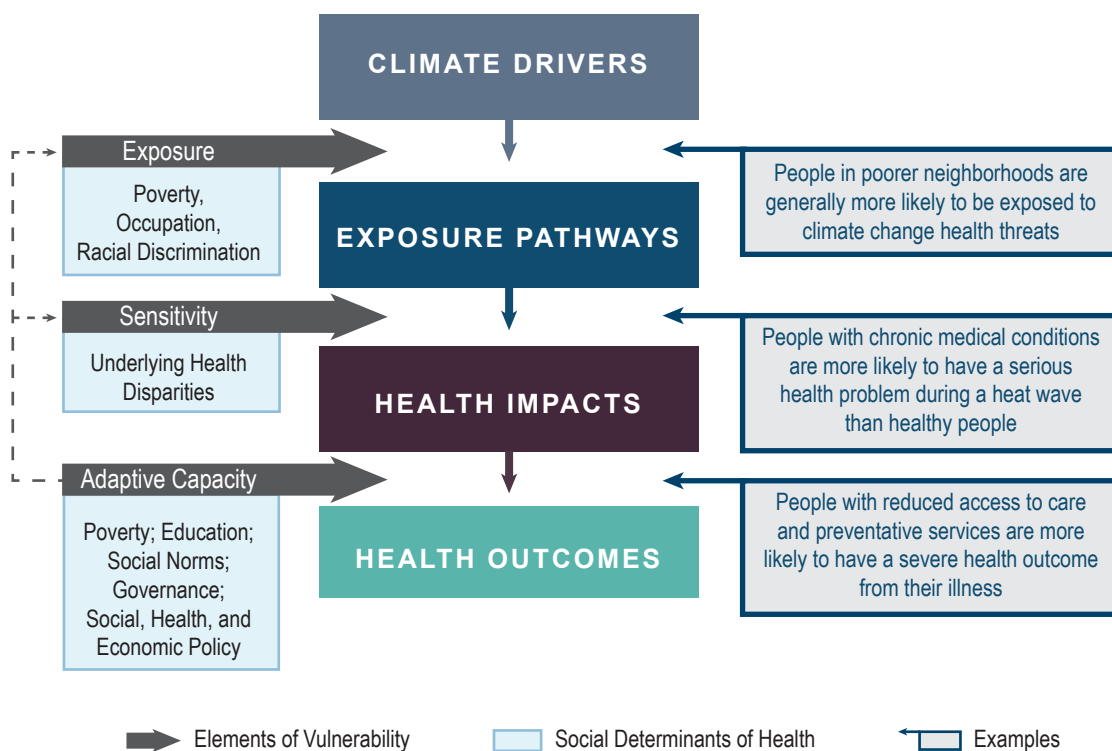


Figure 2: Social determinants of health interact with the three elements of vulnerability. The left side boxes provide examples of social determinants of health associated with each of the elements of vulnerability. Increased exposure, increased sensitivity and reduced adaptive capacity all affect vulnerability at different points in the causal chain from climate drivers to health outcomes (middle boxes). Adaptive capacity can influence exposure and sensitivity and also can influence the resilience of individuals or populations experiencing health impacts by influencing access to care and preventative services. The right side boxes provide illustrative examples of the implications of social determinants on increased exposure, increased sensitivity, and reduced adaptive capacity.



Nursing students and faculty at Emory University School of Nursing in Atlanta, Georgia, volunteering to give checkups in migrant workers' camps, June 12, 2006.

9.3 Populations of Concern

Communities of Color, Low Income, Immigrants, and Limited English Proficiency Groups

In the United States, some communities of color, low-income groups, people with limited English proficiency (LEP), and certain immigrant groups (especially those who are undocumented) live with many of the factors that contribute to their vulnerability to the health impacts of climate change (see Section 9.2). These populations are at increased risk of exposure given their higher likelihood of living in risk-prone areas (such as urban heat islands, isolated rural areas, or coastal and other flood-prone areas), areas with older or poorly maintained infrastructure, or areas with an increased burden of air pollution.^{24, 25, 26, 27} These groups of people also experience relatively greater incidence of chronic medical conditions, such as cardiovascular and kidney disease, diabetes, asthma, and COPD,^{28, 29, 30} which can be exacerbated by climate-related health impacts.^{24, 31, 32, 33, 34} Socioeconomic and educational factors, limited transportation, limited access to health education, and social isolation related to language deficiencies collectively impede their ability to prepare for, respond to, and cope with climate-related health risks.^{24, 26, 34, 35, 36, 37, 38, 39, 40, 41} These populations also may have limited access to medical care and may not be able to afford medications or other treatments.^{30, 38} For LEP and undocumented persons, high poverty rates, language and cultural barriers, and citizenship status limit access to and use of health care and other social services and make these groups more hesitant to seek out help that might compromise their immigration status in the United States.^{39, 42, 43, 44, 45, 46}

The number of people of color in the United States who may be affected by heightened vulnerability to climate-related health risks will continue to grow. Currently, Hispanics or Latinos, Blacks or African Americans, American Indians and Alaska Natives, Asian Americans, and Native Hawaiians and Pacific Islanders represent 37% of the total U.S. population.^{47, 48} By

2042, they are projected to become the majority.⁴⁹ People of color already constitute the majority in four states (California, Hawaii, New Mexico, and Texas) and in many cities.⁴⁸ Numbers of LEP and undocumented immigrant populations have also increased. In 2011, LEP groups comprised approximately 9% (25.3 million individuals) of the U.S. population aged five and older.⁵⁰ In 2010, approximately 11.2 million people in the United States were undocumented.⁵¹

Vulnerability to Climate-Related Health Stressors

Key climate impacts for some communities of color and low-income, LEP, and immigrant populations include heat waves, other extreme weather events, poor air quality, food safety, infectious diseases, and psychological stressors.

Race is an important factor in vulnerability to climate-related stress, but it can be difficult to isolate the role of race from other related socioeconomic and geographic factors. Some racial minorities are also members of low-income groups, immigrants, and people with limited English proficiency, and it is their socioeconomic status (SES) that contributes most directly to their vulnerability to climate change-related stressors. SES is a measure of a person's economic and social status, often defined by income, education, and occupation. Additional factors such as age, gender, preexisting medical conditions, psychosocial factors, and physical and mental stress are also associated with vulnerability to climate change. Because many of these variables are highly related to one another, statistical models must account for these factors in order to accurately measure the relative importance of various risk factors.^{52, 53} For instance, minority race and low SES are jointly linked to increased prevalence of underlying health conditions that may affect sensitivity to climate change. When adjusted for age, gender, and level of education, the number of potential life-years lost from all causes of death was found to be 35% greater for Blacks than for Whites in the United States,⁵⁴ indicating an independent effect of race.

Extreme heat events. Some communities of color and some low-income, homeless, and immigrant populations are more exposed to heat waves,^{55, 56} as these groups often reside in urban areas affected by heat island effects.^{13, 15, 24, 57} In addition, these populations are likely to have limited adaptive capacity due to a lack of adequately insulated housing, inability to afford or to use air conditioning, inadequate access to public shelters such as cooling centers, and inadequate access to both routine and emergency health care.^{24, 26, 29, 34, 35, 38} These social, economic, and health risk factors give rise to the observed increase in deaths and disease from extreme heat in some immigrant and impoverished communities.^{24, 32, 33} Elevated risks for mortality associated with exposures to high ambient temperatures are also reported for Blacks as compared to Whites,^{32, 40, 58, 59} a finding that persists once air conditioning use is accounted for (see also Ch. 2: Temperature-Related Death and Illness).⁶⁰

Other weather extremes. As observed during and after Hurricane Katrina and Hurricane/Post-Tropical Cyclone Sandy, some communities of color and low-income people experienced increased illness or injury, death, or displacement due to poor-quality housing, lack of access to emergency communications, lack of access to transportation, inadequate access to health care services and medications, limited post-disaster employment, and limited or no health and property insurance.^{61, 62, 63, 64, 65, 66} Following a 2006 flood in El Paso, Texas, Hispanic ethnicity was identified as a significant risk factor for adverse health effects after controlling for other important socioeconomic factors (for example, age and housing quality).⁶⁷ Adaptation measures to address these risk factors—such as providing transportation during evacuations or targeted employment assistance during the recovery phase—may help reduce or eliminate these health impact disparities, but may not be readily available or affordable (see also Ch. 4: Extreme Events).^{61, 62, 63, 65, 66}

Degraded air quality. Climate change impacts on outdoor air quality will increase exposure in urban areas where large proportions of minority, low-income, homeless, and immigrant populations reside. Fine particulate matter and ozone levels already exceed National Ambient Air Quality Standards in many urban areas.^{26, 27, 68, 69} Given the relatively higher rates of cardiovascular and respiratory diseases in low-income urban populations,^{26, 28, 30} these populations are more sensitive to degraded air quality, resulting in increases in illness, hospitalization, and premature death.^{70, 71, 72, 73, 74, 75, 76, 77, 78} In addition, climate change can contribute to increases in aeroallergens, which exacerbate asthma, an illness that is relatively more common among some communities of color and low-income groups. People of color are especially impacted by air pollution due to both disproportionate exposures for persons living in urban areas as well as higher prevalence of underlying diseases, such as asthma and COPD, which increase their inherent sensitivity. In 2000, the prevalence of asthma was 122 per 1,000 Black persons and 104 per 1,000 White persons in the United States. At that time, asthma mortality was approximately three times higher among Blacks as compared to Whites (see also Ch. 1: Introduction; Ch. 3: Air Quality Impacts).⁵⁹

Waterborne and vector-borne diseases. Climate change is expected to increase exposure to waterborne pathogens that cause a variety of illnesses—most commonly gastrointestinal illness and diarrhea (see also Ch. 6: Water-Related Illness). Health risks increase in crowded shelter conditions following floods or hurricanes,⁷⁹ which suggests that some low-income groups living in crowded housing (particularly prevalent among foreign-born or Hispanic populations)⁸⁰ may face increased exposure risk. Substandard or deteriorating water infrastructure (including sewerage, drainage, and storm water systems, and drinking water systems) in both urban and rural low-income areas also contribute to increased risk of expo-

sure to waterborne pathogens.^{81, 82} Low-income populations in some regions may also be more vulnerable to the changes in the distribution of some vector-borne diseases that are expected to result from climate change. For example, higher incidence of West Nile virus disease has been linked to poverty and to urban location in the southeastern and northeastern United States, respectively (see also Ch. 5: Vector-Borne Diseases).^{83, 84}

Food safety and security. Climate change affects food safety and is projected to reduce the nutrient and protein content of some crops, like wheat and rice. Some communities of color and low-income populations are more likely to be affected because they spend a relatively larger portion of their household income on food compared to more affluent households. These groups often suffer from poor-quality diets and limited access to full-service grocery stores that offer healthy and affordable dietary choices (see also Ch. 7: Food Safety).^{36, 37, 85, 86}

Psychological stress. Some communities of color, low-income populations, immigrants, and LEP groups are more likely to experience stress-related mental health impacts, particularly during and after extreme events. Other contributing factors include barriers in accessing and affording mental health care, such as counseling in native languages, and the availability and affordability of appropriate medications (see also Ch. 8: Mental Health).^{87, 88}

Indigenous Peoples in the United States

A number of health risks are higher among Indigenous populations, such as poor mental health related to historical or personal trauma, alcohol abuse, suicide, infant/child mortality, environmental exposures from pollutants or toxic substances, and diabetes caused by inadequate or improper diets.^{89, 90, 91, 92, 93, 94, 95, 96} 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. Indigenous Arctic communities have already experienced difficulty adapting to climate change effects such as reductions in sea ice thickness, thawing permafrost, increases in coastal erosion^{97, 98, 99, 100} and landslide frequency,¹⁰¹ alterations in the ranges of some fish,¹⁰² increased weather unpredictability,¹⁰³ and northward advance of the tree line.¹⁰⁴ These climate changes have disrupted traditional hunting and subsistence practices and may threaten infrastructure such as the condition of housing, transportation, and pipelines,¹⁰³ which ultimately may force relocation of villages.¹⁰⁵

Food safety and security. Examples of how climate changes can affect the health of Indigenous peoples include changes in the abundance and nutrient content of certain foodstuffs,

such as berries for Alaska Native communities;¹⁰⁶ declining moose populations in Minnesota, which are significant to many Ojibwe peoples and an important source of dietary protein;^{107, 108} rising temperatures and lack of available water for farming among Navajo people;¹⁰⁹ and declines in traditional rice harvests among the Ojibwe in the Upper Great Lakes region.¹¹⁰ Traditional foods and livelihoods are embedded in Indigenous cultural beliefs and subsistence practices.^{111, 112, 113, 114, 115, 116, 117} Climate impacts on traditional foods may result in poor nutrition and increased obesity and diabetes.¹¹⁸

Changes in aquatic habitats and species also affect subsistence fishing.¹¹⁹ Rising temperatures affect water quality and availability. Lower oxygen levels in freshwater and seawater degrade water quality and promote the growth of disease-causing bacteria, viruses, and parasites.¹²⁰ Warming can exacerbate shellfish disease and make mercury more readily absorbed in fish tissue. Elevated sea surface temperatures, consistent with projected trends in climate warming, have been associated with increased accumulation of methylmercury in fish and increased human exposure.¹²¹ Mercury is a neurotoxin that adversely affects people at all life stages, particularly during the prenatal stage (see also Ch. 6: Water-Related Illness; Ch. 7: Food Safety).^{121, 122, 123} In addition, oceans are becoming more acidic as they absorb some of the carbon dioxide (CO₂) added to the atmosphere by fossil fuel burning and other sources, and this change in acidity can lower shellfish survival.¹²⁰ This affects Indigenous peoples on the West and Gulf Coasts and Alaska Natives whose livelihoods depend on shellfish harvests.¹²⁴ Rising sea levels will also destroy fresh and saltwater habitats that some Indigenous peoples located along the Gulf Coast rely upon for subsistence food.¹²⁵

Water security. Indigenous peoples may lack access to water resources and to adequate infrastructure for water treatment and supply. A significant number of Indigenous persons living on remote reservations lack indoor plumbing and rely on unregulated water supplies that are vulnerable to drought, changes in water quality, and contamination of water in local systems.^{109, 126} Existing infrastructure may be poorly maintained or in need of significant and costly upgrades.¹²⁷ Heavy rainfall events and warm temperatures have been linked to diarrheal outbreaks and bacterial contamination of drinking water sources (see Ch. 6: Water-Related Illness). Acute diarrheal disease has been shown to disproportionately affect children on the Fort Apache reservation in Arizona,¹²⁸ and result in higher overall hospitalization rates for American Indian/Alaska Native infants.¹²⁹ Increased extreme precipitation and potential increases in cyanobacterial blooms (see Ch. 6: Water-Related



Indigenous deckhand pulls in net of geoducks near Suquamish, Washington, January 17, 2007. Traditional foods and livelihoods are embedded in Indigenous cultural beliefs and subsistence practices.

Illness) are also expected to stress existing water infrastructure on tribal lands and increase exposure to waterborne pathogens.^{122, 130}

Loss of cultural identity. Climate change threatens sacred ceremonial and cultural practices through changing the availability of culturally relevant plant and animal species.^{95, 130} Climate-related threats may compound historical impacts associated with colonialism, as well as current effects on tribal culture as more young people leave reservations for education and employment opportunities. Loss of tribal territory and disruption of cultural resources and traditional ways of life^{131, 132} lead to loss of cultural identity.^{133, 134, 135} The loss of medicinal plants due to climate change may leave ceremonial and traditional practitioners without the resources they need to practice traditional healing.^{114, 136} The relocation of young people may reduce interactions across generations and undermine the sharing of traditional knowledge, tribal lore, and oral history.^{137, 138}

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.

Degraded infrastructure and other impacts. Rising temperatures may damage transportation infrastructure on tribal lands. Changing ice or thawing permafrost, flooding, and drought-related dust storms may block roads and cut off communities from access to evacuation routes and emergency medical care or social services.¹³⁹ Poor air quality from blowing dust affects southwestern Indigenous communities, particularly in Arizona and New Mexico, and is likely to worsen with drought conditions.¹⁴⁰ Exposure to impaired air quality also affects Indigenous communities, especially those downwind from urban areas or industrial complexes.

Children and Pregnant Women

Children are vulnerable to adverse health effects associated with environmental exposures due to factors related to their immature physiology and metabolism, their unique exposure pathways, their biological sensitivities, and limits to their adaptive capacity. Children pass through a series of windows of vulnerability that begin in the womb and continue through their second decade of life. Children have a proportionately higher intake of air, food, and water relative to their body weight compared to adults.²⁰ They also share unique behaviors and interactions with their environment that may increase their exposure to environmental contaminants. For example, small children often play indoors on the floor or outdoors on the ground and place hands and other objects in their mouths, increasing their exposure to dust and other contaminants, such as pesticides, mold spores, and allergens.¹⁴¹ There is, however, large variation in vulnerability among children at different life stages due to differing physiology and behaviors (Figure 3). Climate change—interacting with factors such as economic status, diet, living situation, and stage of development—will increase children’s exposure to health threats.^{12, 21, 142, 143, 144} The impact of poverty on children’s health is a critical factor to consider in ascertaining how climate change will be manifest in children. Poor and low-income households have difficulty accessing health care and meeting the basic needs that are crucial for healthy child development. In addition, children in poverty are less likely to have access to air conditioning to mitigate the effects of extreme heat. Children living in poverty are also less likely to be able to respond to or escape from extreme weather events.^{12, 21, 142, 143, 144}

Vulnerability to Climate-Related Health Stressors

Extreme heat events. An increase in the frequency and intensity of extreme heat events (see Ch. 2: Temperature-Related Death and Illness) will affect children who spend

time outdoors or in non-climate-controlled indoor settings. Student athletes and other children who are susceptible to heat-related illnesses when they exercise or play outdoors in hot and humid weather may be poorly acclimated to physical exertion in the heat. Some 9,000 high school athletes in the United States are treated for exertional heat illness (such as heat stroke and muscle cramps) each year, with the greatest risk among high school football players.^{145, 146} This appears to be a worsening trend. Between 1997 and 2006, emergency department visits for all heat-related illness increased 133% and youth made up almost 50% of those cases.¹⁴⁷ From 2000 through 2013, the number of deaths due to heat stroke doubled among U.S. high school and college football players.¹⁴⁸ Other data show effects of extreme heat on children of all ages, including increases in heat illness, fluid and electrolyte imbalances, and asthma. Children in homes or schools without air conditioning are also more vulnerable during heat events.

Other weather extremes. Climate change is likely to affect the mental health and well-being of children, primarily by increasing exposure to traumatic weather events that result in injury, death, or displacement. In 2003, more than 10% of U.S. children from infancy to 18 years of age reported experiencing a disaster (fire, tornado, flood, hurricane, earthquake, etc.) during their lifetimes.¹⁴⁹ Exposures to traumatic events can impact children’s capacity to regulate emotions, undermine cognitive development and academic performance, and contribute to post-traumatic stress disorder (PTSD) and other psychiatric disorders (such as depression, anxiety, phobia, and panic).¹⁵⁰ Children’s ability to cope with disasters is affected by factors such as socioeconomic status, available support systems, and timeliness of treatment. Negative mental health effects in children, if untreated, can extend into adulthood.¹⁵⁰ (See Ch. 4: Extreme Events; Ch. 8: Mental Health).

Vulnerability to the Health Impacts of Climate Change at Different Life Stages.

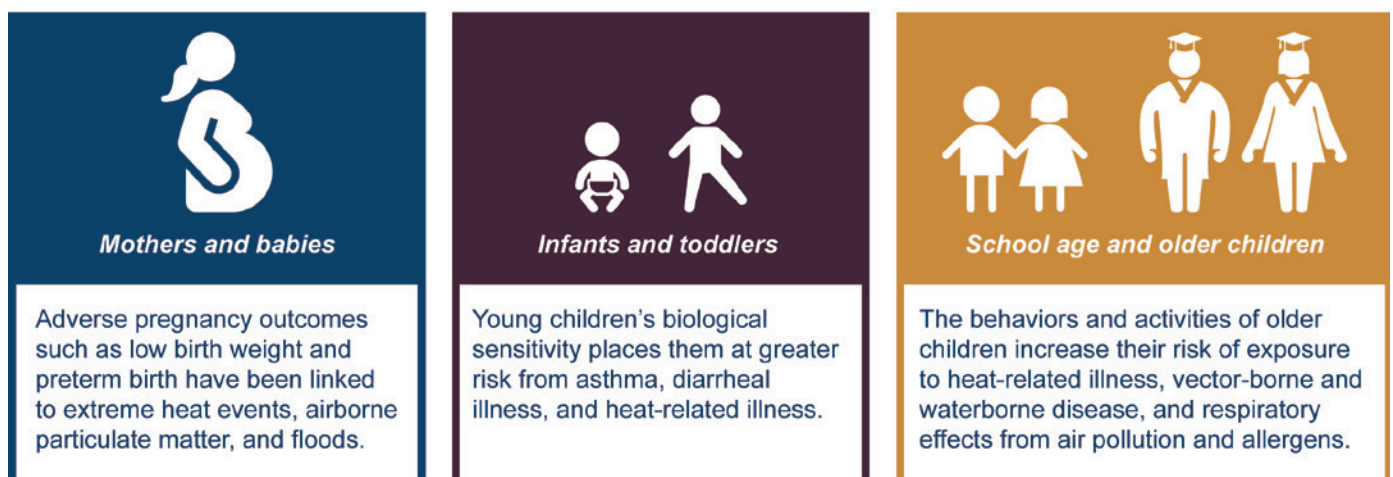


Figure 3: Children’s vulnerability to climate change results from distinct exposures, biological sensitivities (developing bodies and immune systems), and limitations to adaptive capacity (dependency on caregivers) at different life stages.



Climate-related exposures may lead to adverse pregnancy and newborn health outcomes.

Degraded air quality. Several factors make children more sensitive to the effects of respiratory hazards, including lung development that continues through adolescence, the size of the child's airways, their level of physical activity, and body weight. Climate change has the potential to affect future ground-level ozone concentrations, particulate matter concentrations, and levels of some aeroallergens. Ground-level ozone and particulate matter are associated with increases in asthma episodes and other adverse respiratory effects in children.^{151, 152, 153} Nearly seven million, or about 9%, of children in the United States, suffer from asthma.¹⁵⁴ Asthma accounts for 10 million missed school days each year.¹⁵⁵ Particulate matter such as dust and emissions from coal-fired electricity generation plants is also associated with decreases in lung maturation in children.¹⁵⁶

Changes in climate also contribute to longer, more severe pollen seasons that may be associated with increases in childhood asthma episodes and other allergic illnesses. Children may also be exposed to indoor air pollutants, including both particulate matter originating outdoors and indoor sources such as tobacco smoke and mold. In addition, high outdoor temperatures may increase the amount of time children spend indoors. Homes, childcare centers, and schools—places where children spend large amounts of their time—are all settings where indoor air quality issues may affect children's health. In communities where these buildings are insufficiently supplied with screens, air conditioning, humidity controls, or pest control, children's health may be at risk.¹⁵⁷ (See Ch. 3: Air Quality Impacts).

Waterborne illnesses. Climate change induced increases in heavy rainfall, flooding, and coastal storm events are expected to increase children's risk of gastrointestinal illness from ingestion of or contact with contaminated water.^{61, 142, 143, 158} An increased association between heavy rainfall and increased acute gastrointestinal illness has already been observed in children in the United States.¹⁵⁹ Children may be especially vulnerable to recreational exposures to waterborne pathogens, in part because they swallow roughly twice as much water as adults while swimming.¹⁶⁰ In addition, children comprised

40% of swimming-related eye and ear infections from the waterborne bacteria *Vibrio alginolyticus* during the period 1997–2006¹⁶¹ and 66% (ages 1–19) of those seeking treatment for illness associated with harmful algal bloom toxins in 2009–2010.¹⁶² (See Ch. 6. Water-Related Illness).

Vector-Borne and other infectious diseases. The changes in the distribution of infectious diseases that are expected to result from climate change may introduce new exposures to children (see Ch. 5: Vector-Borne Disease). Due to physiological vulnerability or changes in their body's immune system, fetuses, pregnant women, and children are at increased risk of acquiring or having complications from certain infectious diseases such as listeriosis,¹⁶³ dengue fever,¹⁶⁴ and influenza.¹⁶⁵ Children spend more time outdoors than adults, increasing their exposure to mosquito and tick bites that can cause vector-borne diseases that disproportionately affect children such as La Crosse encephalitis or Lyme disease.^{21, 143, 166} Lyme disease is most frequently reported among male children aged 5 to 9 years, and a disproportionate increasing trend was observed in all children from 1992 to 2006.^{167, 168}

Food safety and security. Climate change, including rising levels of atmospheric CO₂, significantly reduces food quality and threatens availability and access for children. Because of the importance of nutrition during certain stages of physical and mental growth and development, the direct effect of the continued rise of CO₂ on reducing food quality will be an increasingly significant issue for children globally.^{169, 170, 171} For the United States, disruptions in food production or distribution due to extreme events such as drought can increase costs and limit availability or access,^{172, 173} particularly for food-insecure households, which include nearly 16% of households with children in the United States.¹⁷⁴ Children are also more susceptible to severe infection or complications from *Escherichia coli* infections, such as hemolytic uremic syndrome.¹⁷⁵ (See Ch. 7: Food Safety).

Vulnerability Related to Life Stage

Prenatal and pregnancy outcomes for mothers and babies. Climate-related exposures may lead to adverse pregnancy and newborn health outcomes, including spontaneous abortion, low birth weight (less than 5.5 pounds), preterm birth (birth before 37 weeks of pregnancy), increased neonatal death, dehydration and associated renal failure, malnutrition, diarrhea, and respiratory disease.^{21, 176} Other risk factors that may influence maternal and newborn health include water scarcity, poverty, and population displacement.^{21, 176} The rate of preterm births is relatively high in the United States (1 of every 9 infants born),¹⁷⁷ where they contribute substantially to neonatal death and illness. Of the 1.2 million preterm births estimated to occur annually in high-income countries, more than 500 thousand (42% of the total) occur in the United States.¹⁷⁸ Extreme heat events have been associated with adverse birth outcomes such as low birth weight, preterm birth,

and infant mortality,^{179, 180, 181} as well as congenital cataracts.¹⁸² Newborns are especially sensitive to ambient temperatures that are too high or too low because their capacity for regulating body temperature is limited.¹⁸³

In addition, exposure of pregnant women to inhaled particulate matter is associated with negative birth outcomes.^{184, 185, 186, 187, 138 :99} Incidences of diarrheal diseases and dehydration may increase in extent and severity, which can be associated with adverse effects on pregnancy outcomes and the health of newborns.¹⁷⁶ Floods are associated with an increased risk of maternal exposure to environmental toxins and mold, reduced access to safe food and water, psychological stress, and disrupted health care. Other flood-related health outcomes for mothers and babies include maternal risk of anemia (a condition associated with low red blood cell counts sometimes caused by low iron intake), eclampsia (a condition that can cause seizures in pregnant women), and spontaneous abortion.^{190, 191, 192, 193}

Infants and toddlers. Infants and toddlers are particularly sensitive to air pollutants, extreme heat, and microbial water contamination, which are all affected by climate change. Ozone exposure in young children and exposure to air pollutants and toxins in wildfire smoke are associated with increased asthma risk and other respiratory illnesses.^{78, 142} Young children and infants are particularly vulnerable to heat-related illness and death, as their bodies are less able to adapt to heat than are adults.^{32, 40, 58, 143, 194} Children under four years of age experience higher hospital admissions for respiratory illnesses during heat waves.¹⁹⁵ Rates of diarrheal illness have been shown to be higher in children under age five in the United States,¹⁹⁶ and climate change is expected to increase children's risk of gastrointestinal illness from ingestion or contact with contaminated water (see also Ch. 6: Water-Related Illness).^{61, 142, 143, 158}

Older Adults

Older adults (generally defined as persons aged 65 and older) are vulnerable to the health impacts associated with climate change and weather extremes.^{12, 197, 198, 199} The number of older adults in the United States is projected to grow substantially in the coming decades. The nation's older adult population (ages 65 and older) will nearly double in number from 2015 through 2050, from approximately 48 million to 88 million.²⁰⁰ Of those 88 million older adults, a little under 19 million will be 85 years of age and older.²⁰¹ This projected population growth is largely due to the aging of the Baby Boomer generation (an estimated 76 million people born in the United States between 1946 and 1964), along with increases in lifespan and survivorship.¹⁹ Older adults in the United States are not uniform with regard to their climate-related vulnerabilities, but are a diverse group with distinct subpopulations that can be identified not only by age but also by race, educational attainment, socioeconomic status, social support networks, overall physical and mental health, and disability status.^{198, 202}

Vulnerability to Climate-Related Health Stressors

The potential climate change related health impacts for older adults include rising temperatures and heat waves; increased risk of more intense hurricanes (Categories IV and V), floods, droughts, and wildfires; degraded air quality; exposure to infectious diseases; and other climate-related hazards.¹²⁰

Extreme heat events. Older adults exposed to extreme heat can experience multiple adverse effects.²⁰³ In the coming decades, extreme heat events are projected to become more frequent, more intense, and of longer duration, especially in higher latitudes and large metropolitan areas.^{24, 204} Between 1979 and 2004, 5,279 deaths were reported in the United States related to heat exposure, with those deaths reported most commonly among adults aged 65 and older.²⁰⁵ Disease incidence among older adults is expected to increase even in regions with relatively modest temperature changes (as demonstrated by case studies of a 2006 California heat wave).⁴⁰ In New York City, extreme high temperatures were associated with an increase in hospital admissions for cardiovascular and respiratory disorders, with the elderly among the most affected. Hospital admissions for respiratory illness were greatest for the elderly, with a 4.7% increase per degree Centigrade increase.³³ Future climate-related increases in summertime temperatures may increase the risk of death in older people with chronic conditions, particularly those suffering from congestive heart failure and diabetes.²⁰⁶ The percentage of older adults with diabetes, which puts individuals at higher risk for heat-related illness and death, has increased from 9.1% in 1980 to 19.9% in 2009.²⁰⁷

Other weather extremes. Hurricanes and other severe weather events lead to physical, mental, or emotional trauma before, during, and after the event.²⁰⁸ The need to evacuate an area can pose increased health and safety risks for older adults, especially those who are poor or reside in nursing or assisted-living facilities.^{209, 210} Moving patients to a sheltering facility is complicated, costly, and time-consuming and requires concurrent transfer of medical records, medications, and medical equipment (see also Ch. 4: Extreme Events).^{210, 211}

Degraded air quality. Climate change can affect air quality by increasing ground-level ozone, fine particulate matter, aeroallergens, wildfire smoke, and dust (see Ch. 3: Air Quality Impacts).^{212, 213} Exposure to ground-level ozone varies with age and can affect lung function and increase emergency department visits and hospital admissions, even for healthy adults. Air pollution can also exacerbate asthma and COPD and can increase the risk of heart attack in older adults, especially those who are also diabetic or obese.²¹⁴

Vector-Borne and waterborne diseases. The changes in the distribution of disease vectors like ticks and mosquitoes that are expected to result from climate change may increase exposures to pathogens in older adult populations (see Ch. 5:

Vector-Borne Diseases). Some vector-borne diseases, notably mosquito-borne West Nile and St. Louis encephalitis viruses,^{215, 216} pose a greater health risk among sensitive older adults with already compromised immune systems. Climate change is also expected to increase exposure risk to waterborne pathogens in sources of drinking water and recreational water. Older adults have a higher risk of contracting gastrointestinal illnesses from contaminated drinking and recreational water and suffering severe health outcomes and death (see Ch. 6: Water-Related Illness).^{217, 218, 219, 220}

Interactions with Non-Climate Stressors

Vulnerability related to locations and condition of the built environment.

Older adults are particularly vulnerable to climate change related health effects depending on their geographic location and characteristics of their homes, such as the quality of construction and amenities. More than half of the elderly U.S. adult population is concentrated in 170 counties (5% of all U.S. counties), and approximately 20% of older Americans live in a county in which a hurricane or tropical storm made landfall over the last decade.²²¹ For example, Florida is a traditional retirement destination with an older adult population accounting for 16.8% of the total in 2010, nearly four percentage points higher than the national average.²²² The increasing severity of tropical storms may pose particular risks for older adults in coastal zones.²²³ Other geographic risk factors common to older adults are the urban heat island effect, urban sprawl (which affects mobility), characteristics of the built environment, and perceptions of neighborhood safety.^{224, 225}

In neighborhoods where safety and crime are a concern, older residents may fear venturing out of their homes, thus increasing their social isolation and risk of health impacts during events such as heat waves.²²⁴ Degraded infrastructure, including the condition of housing and public transportation, is associated with higher numbers of heat-related deaths in older adults. In multi-story residential buildings in which residents rely on elevators, electricity loss makes it difficult, if not impossible, for elderly residents and those with disabilities to leave the building to obtain food, medicine, and other needed services.²²⁶ Also, older adults who own air-conditioning units may not utilize them during heat waves due to high operating costs.^{12, 227, 228, 229}

Vulnerability related to physiological factors. Older adults are more sensitive to weather-related events due to age-related physiological factors. Elevated risks for cardiovascular deaths related to exposure to extreme heat have been observed in older adults.^{32, 230} Generally poorer physical health conditions, such as long-term chronic illnesses, are exacerbated by climate change.^{227, 228, 231, 232} In addition, aging can impair the mechanisms that regulate body temperature, particularly for those taking medications that interfere with regulation of body temperature, including psychotropic medications used to treat a variety of mental illnesses such as depression, anxiety, and psy-

chosis.²³³ Respiratory impairments already experienced by older adults will be exacerbated by increased exposure to outdoor air pollutants (especially ozone and fine particulate matter), aeroallergens, and wildfire smoke—all of which may be exacerbated by climate change.^{199, 213}

Vulnerability related to disabilities. Some functional limitations and mobility impairments increase older adults' sensitivity to climate change, particularly extreme events. In 2010, 49.8% of older adults (over 65) were reported to have a disability, compared to 16.6% of people aged 21–64.²³⁴ Dementia occurs at a rate of 5% of the U.S. population aged 71 to 79 years, with an increase to more than 37% at age 90 and older.²³⁵ Older adults with mobility or cognitive impairments are likely to experience greater vulnerability to health risks due to difficulty responding to, evacuating, and recovering from extreme events.^{12, 231}

Occupational Groups

Climate change may increase the prevalence and severity of known occupational hazards and exposures, as well as the emergence of new ones. Outdoor workers are often among the first to be exposed to the effects of climate change. Climate change is expected to affect the health of outdoor workers through increases in ambient temperature, degraded air quality, extreme weather, vector-borne diseases, industrial exposures, and changes in the built environment.¹¹ Workers affected by climate change include farmers, ranchers, and other agricultural workers; commercial fishermen; construction workers; paramedics, firefighters and other first responders; and transportation workers. Also, laborers exposed to hot indoor work environments (such as steel mills, dry cleaners, manufacturing facilities, warehouses, and other areas that lack air conditioning) are at risk for extreme heat exposure.^{236, 237, 238}

For some groups, such as migrant workers and day laborers, the health effects of climate change can be cumulative, with occupational exposures exacerbated by exposures associated with poorly insulated housing and lack of air conditioning. Workers may also be exposed to adverse occupational and climate-related conditions that the general public may altogether avoid, such as direct exposure to wildfires.

Extreme heat events. Higher temperatures or longer, more frequent periods of heat may result in more cases of heat-related illnesses (for example, heat stroke and heat exhaustion) and fatigue among workers,^{237, 238, 239, 240, 241} especially among more physically demanding occupations. Heat stress and fatigue can also result in reduced vigilance, safety lapses, reduced work capacity, and increased risk of injury. Elevated temperatures can increase levels of air pollution, including ground-level ozone, resulting in increased worker exposure and subsequent risk of respiratory illness (see also Ch. 2: Temperature-Related Death and Illness).^{11, 236, 237, 242}

Other weather extremes. Some extreme weather events and natural disasters, such as floods, storms, droughts, and wildfires, are becoming more frequent and intense (see also Ch. 4: Extreme Events).¹²⁰ An increased need for complex emergency responses will expose rescue and recovery workers to physical and psychological hazards.^{205, 243} The safety of workers and their ability to recognize and avoid workplace hazards may be impaired by damage to infrastructure and disrupted communication.

From 2000 to 2013, almost 300 U.S. wildfire firefighters were killed while on duty.²⁴⁴ With the frequency and severity of wildfires projected to increase, more firefighters will be exposed. Common workplace hazards faced on the fire line include being overrun by fire (as happened during the Yarnell Hill Fire in Arizona in 2013 that killed 19 firefighters);²⁴⁵

heat-related illnesses and injuries; smoke inhalation; vehicle-related injuries (including aircraft); slips, trips, and falls; and exposure to particulate matter and other air pollutants in wildfire smoke. In addition, wildland fire fighters are at risk of rhabdomyolysis (a breakdown of muscle tissue) that is associated with prolonged and intense physical exertion.²⁴⁶

Other workplace exposures to outdoor health hazards. Other climate-related health threats for outdoor workers include increased waterborne and foodborne pathogens, increased duration of aeroallergen exposure with longer pollen seasons,^{247, 248} and expanded habitat ranges of disease-carrying vectors that may influence the risk of human exposure to diseases such as West Nile virus or Lyme disease (see also Ch. 5: Vector-Borne Diseases).²⁴⁹

Vulnerability of the U.S. Armed Forces

Another emerging area of interest, but one where research is limited and key research questions remain, is the relationship between climate change and occupational safety and health hazards posed to members of the U.S. Armed Forces. The U.S. Department of Defense (DoD) recognizes that climate change will affect its operating environment, roles, and missions both within the United States and abroad.^{250, 251, 252} The DoD faces unique challenges in protecting the health of its personnel from climate change impacts.

Military personnel who train and conduct operations in hot environments are at risk for heat-related illness. The incidence of heat illness among active duty U.S. military personnel is several-fold higher than the summertime incidence in the general U.S. population (147 per 100,000 among the military versus 21.5 per 100,000 in the general population per year).^{253, 254} A large proportion of military heat illness cases occur in training settings in the southern United States,²⁵³ where climate change may increase future risk.

Exposure to some climate-sensitive infectious diseases also may be increased among military personnel who work extensively in field settings. For example, Lyme disease is the most commonly reported vector-borne disease in the list of Armed Forces Reportable Medical events, which covers diseases that may represent significant threats to public health and military operations. Lyme disease incidence is highest in military units in the Northeast United States, and in some cases is substantially higher than the Centers for Disease Control and Prevention (CDC) estimates for the population of the state in which the unit is located.²⁵⁵ Coccidioidomycosis, or “valley fever,” caused by inhalation of fungal spores, is an occupational hazard for military personnel training in the southwestern United States or other endemic areas (see also Ch 4: Extreme Events).^{256, 257} Military personnel are stationed and deployed globally, and may face higher risk of climate-sensitive infections that are rare in the United States. Recent examples include chikungunya,^{258, 259} dengue fever,²⁶⁰ leishmaniasis,²⁶¹ and malaria.^{262, 263, 264, 265}

The DoD’s climate change adaptation plan includes several health-related initiatives to understand and mitigate such threats, including assessment of projected climate change on health risks to DoD personnel, health surveillance demands, and distribution of disease vectors, among others.²⁵⁰



Soldiers race for first place during an annual physical training competition in Fort Riley, Kansas.

Persons with Disabilities

Disability refers to any condition or impairment of the body or mind that limits a person's ability to do certain activities or restricts a person's participation in normal life activities, such as school, work, or recreation.²⁶⁶ The term "disability" covers a wide variety and range of functional limitations related to expressive and receptive communication (hearing and speech), vision, cognition, and mobility. These factors, if not anticipated and accommodated before, during, and after extreme events, can result in illness and death.²⁶⁷ The extent of disability, or its severity, is reflected in the affected person's need for environmental accessibility and accommodations for their impairment(s).²⁶⁸

Disability can occur at any age and is not uniformly distributed across populations. Disability varies by gender, race, ethnicity, and geographic location.²⁶⁹ Approximately 18.7% of the U.S. population has a disability.²³⁴ In 2010, the percent of American adults with a disability was approximately 16.6% for those aged 18–64 and 49.8% for persons 65 and older.²³⁴ In 2014, working-age adults with disabilities were substantially less likely to participate in the labor force (30.2%) than people without disabilities (76.2%), and experience more than twice the rate of unemployment (13.9% and 6.0%, respectively).²⁷⁰

People with disabilities experience disproportionately higher rates of social risk factors, such as poverty and lower educational attainment, that contribute to poorer health outcomes during extreme events or climate-related emergencies. These factors compound the risks posed by functional impairments and disrupt planning and emergency response. Of the climate-related health risks experienced by people with disabilities, perhaps the most fundamental is their "invisibility" to decision-makers and planners.²⁷¹ There has been relatively limited empirical research documenting how people with disabilities fare during or after an extreme event.²⁷²

An increase in extreme weather can be expected to disproportionately affect populations with disabilities unless emergency planners make provisions to address their functional needs in preparing emergency response plans. In 2005, Hurricane Katrina had a significant and disproportionate impact on people with disabilities. Of the 986 deaths in Louisiana directly attributable to the storm, 103 occurred among individuals in nursing homes, presumably with a disability.²⁷³ Strong social capital and societal connectedness to other people, especially through faith-based organizations, family networks, and work connections, were considered to be key enabling factors that helped people with disabilities to cope before, during, and

after the storm.²⁷⁴ In the aftermath of Hurricane Sandy, the City of New York lost a lawsuit filed by the Brooklyn Center for Independence of the Disabled (*Brooklyn Center for Independence of the Disabled et al. v. Bloomberg et al.*, Case 1:11-cv-06690-JMF 2013), with the finding that the city had not adequately prepared to accommodate the social and medical

support needs of New York residents with disabilities.

Risk communication is not always designed or delivered in an accessible format or media for individuals who are deaf or have hearing loss, who are blind or have low vision, or those with diminished cognitive skills.^{275, 276} Emergency communication and other important notifications

(such as a warning to boil contaminated water) simply may not reach persons with disabilities. In addition, persons with disabilities often rely on medical equipment (such as portable oxygen) that requires an uninterrupted source of electricity. Portable oxygen supplies must be evacuated with the patient.²⁷⁷

People with disabilities experience disproportionately higher rates of social risk factors, such as poverty and lower educational attainment, that contribute to poorer health outcomes during extreme events or climate-related emergencies.

Persons with Chronic Medical Conditions

Preexisting medical conditions present risk factors for increased illness and death associated with climate-related stressors, especially exposure to extreme heat. In some cases, risks are mediated by the physiology of specific medical conditions that may impair responses to heat exposure. In other cases, the risks are related to unintended side effects of med-



Persons with disabilities often rely on medical equipment (such as portable oxygen) that requires an uninterrupted source of electricity.

ical treatment that may impair body temperature, fluid, or electrolyte balance and thereby increase risks. Trends in the prevalence of chronic medical conditions are summarized in Table 1 in Chapter 1: Introduction. In general, the prevalence of common chronic medical conditions, including cardiovascular disease, respiratory disease, diabetes, asthma, and obesity, is anticipated to increase over the coming decades (see Table 1 in Ch. 1: Introduction), resulting in larger populations at risk of medical complications from climate change related exposures.

Excess heat exposure has been shown to increase the risk of disease exacerbation or death for people with various medical conditions. Hospital admissions and emergency room visits increase during heat waves for people with diabetes, cardiovascular diseases, respiratory diseases, and psychiatric illnesses.^{40, 58, 195, 278, 279, 280, 281, 282} Medical conditions like Alzheimer's disease or mental illnesses can impair judgment and behavioral responses in crisis situations, which can place people with those conditions at greater risk.²²⁸

Medications used to treat chronic medical conditions are associated with increased risk of hospitalization, emergency room admission, and in some cases, death from extreme heat. These medicines include drugs used to treat neurologic or psychiatric conditions, such as anti-psychotic drugs, anti-cholinergic agents, anxiolytics (anti-anxiety medicines), and some antidepressants (such as selective serotonin reuptake inhibitors or SSRIs; see also Ch. 8: Mental Health).^{233, 283, 284} In addition, drugs used to treat cardiovascular diseases, such as diuretics and beta-blockers, may impair resilience to heat stress.^{283, 285}

People with chronic medical conditions also can be more vulnerable to interruption in treatment. For example, interrupting treatment for patients with addiction to drugs or alcohol may lead to withdrawal syndromes.^{286, 287, 288} Treatment for chronic medical conditions represents a significant proportion of post-disaster medical demands.²⁸⁹ Communities that are both medically underserved and have a high prevalence of chronic medical conditions can be especially at risk.²⁹⁰ While most studies have assessed adults, and especially the elderly, with chronic medical conditions, children with medical conditions such as allergic and respiratory diseases are also at greater risk of symptom exacerbation and hospital admission during heat waves.¹⁴⁴

9.4 Measures of Vulnerability and Mapping

Vulnerability associated with exposures to climate-related hazards is closely tied to place. While an understanding of the individual-level factors associated with vulnerability is essential to assessing population risks and considering possible protective measures, understanding how potential exposures overlap with the geographic location of populations of concern is critical for designing and implementing appropri-

ate adaptations. Analytic capabilities provided by mapping tools allow public health and emergency response workers to consider multiple types of vulnerability and how they interact with place. The development of indices that combine different elements of vulnerability and allow visualization of areas and populations experiencing the highest risks is related to improved geographic information systems (GIS) capabilities.²⁹¹

There are multiple approaches for developing vulnerability indices to identify populations of concern across large areas, such as state or multistate regions, or small areas, such as households within a county or several counties within a state.²⁹³ The Social Vulnerability Index (SVI) developed by the CDC aggregates U.S. census data to estimate the social vulnerability of census tracts (which are generally subsets of counties; Figure 4). The SVI provides a measure of overall social vulnerability in addition to measures of elements that comprise social vulnerability (including socioeconomic status, household composition, race or ethnicity, native language, and infrastructure conditions). Each census tract receives a separate ranking for overall vulnerability and for each of the four elements, which are available at the census-tract level for the entire United States. A similar methodology has been

Mapping Social Vulnerability

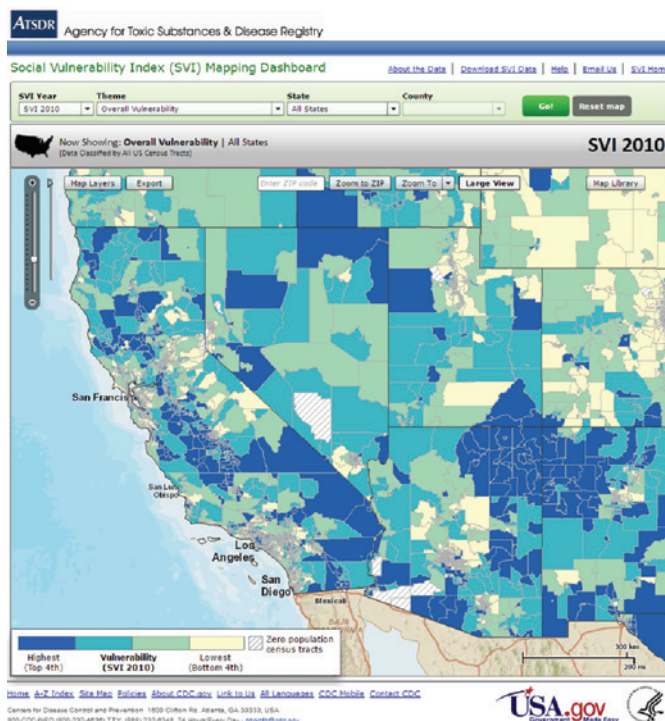


Figure 4: CDC Social Vulnerability Index (SVI): This interactive web map shows the overall social vulnerability of the U.S. Southwest in 2010. The SVI provides a measure of four social vulnerability elements: socioeconomic status; household composition; race, ethnicity, and language; and housing/transportation. Each census tract receives a separate ranking for overall vulnerability at the census-tract level. Dark blue indicates the highest overall vulnerability (the top quartile) with the lowest quartile in pale yellow. (Figure source: ATSDR 2015)²⁹²

Mapping Heat Vulnerability in Georgia

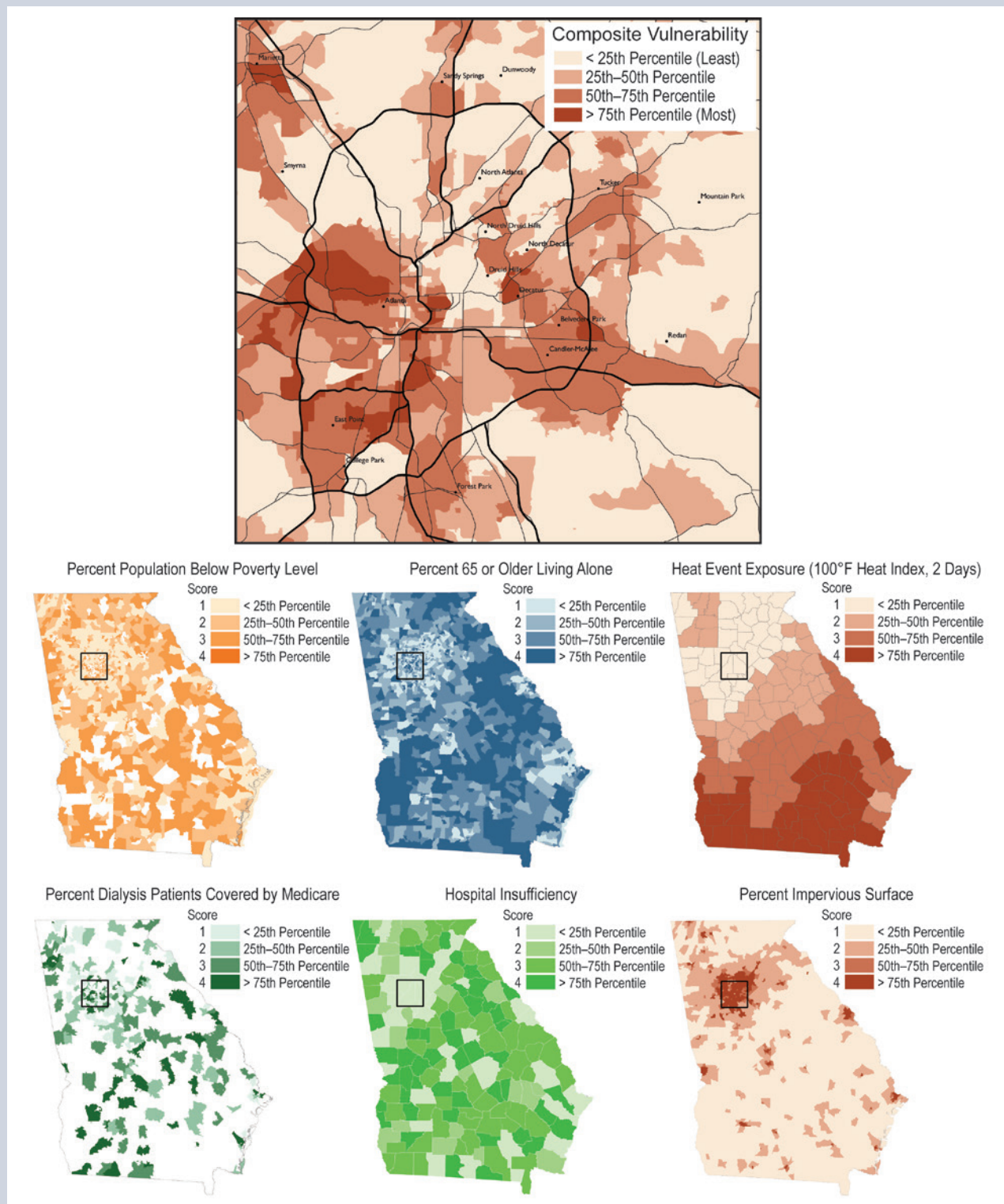


Figure 5: Vulnerability to heat-related illness in Georgia extends beyond urban zones. The map on top shows a composite measure of social vulnerability for the Atlanta, Georgia Metropolitan Area (darkest colors indicate the most vulnerable areas). The six state-wide maps below show the following six vulnerability factors: 1) percent population below the poverty level, 2) percent aged 65 and older living alone, 3) heat event exposure with Heat Index over 100°F for two consecutive days, 4) percent dialysis patients on Medicare, 5) hospital insufficiency based upon accessibility of hospital infrastructure, and 6) percent impervious surface. Areas located in rural southern Georgia experienced more hazardous heat events, had less access to health care, and had a higher percentage of people living alone. (Figure source: adapted from Manangan et al. 2014)²⁹⁴

Mapping Heat Vulnerability in Georgia, continued

The CDC conducted a case study of heat-related vulnerability in Georgia using data from 2002 to 2008. This climate and health vulnerability assessment, which identifies people and places that are most susceptible to hazardous exposures from climate change, uses GIS to overlay six maps depicting population-level sensitivity (poverty levels, elderly people living alone, preexisting health conditions, and people living in urban areas), adaptive capacity (a measure of access to healthcare), and exposure (a measure of heat events). The study found that vulnerability to heat-related illness in Georgia extends beyond urban zones. In fact, areas located in the southern portion of Georgia, which is more rural, experienced more hazardous heat events, had less access to health care, and had a higher percentage of people living alone. These types of studies allow researchers to use GIS to identify vulnerable communities, which can aid in the development of public health interventions and other adaptation strategies²⁹⁴ (Figure 5).

used to develop a vulnerability index for climate-sensitive health outcomes which, in addition to socioeconomic data, incorporates data on climate-related exposures and adaptive capacity.²⁹⁴

Application of Vulnerability Indices

GIS—data management systems used to capture, store, manage, retrieve, analyze, and display geographic information—can be used to quantify and visualize factors that contribute to climate-related health risks. By linking together census data, data on the determinants of health (social, environmental, pre-existing health conditions), measures of adaptive capacity (such as health care access), and climate data, GIS mapping helps identify and position resources for at-risk populations.^{4, 10, 294, 295, 296, 297} For instance, heat-related illnesses have been associated with social isolation in older adults, which can be mapped by combining data for persons living alone (determinants of health data), distribution of people aged 65 and older (census data), and frequency and severity of heat waves (climate data).

Vulnerability mapping can also enhance emergency and disaster risk management.^{298, 299} Vulnerability mapping conducted at finer spatial resolution (for example, census tracts or census blocks) allows public health departments to target vulnerable communities for emergency preparedness, response, recovery, and mitigation.³⁰⁰ Geographic characteristics of vulnerability can be used to determine where to position emergency medical and social response resources that are most needed before, during, and after climate change related events.^{298, 299, 300}

Emergency response agencies can apply lessons learned by mapping prior events. For example, vulnerability mapping has been used to assess how social disparities affected the geography of recovery in New Orleans following Hurricane Katrina.⁹ Maps displaying the intersection of social vulnerability (low, medium, high scores) and flood inundation (none, low, medium, high levels) showed that while the physical manifestation of the disaster had few race or class distinctions, the social vulnerability of communities influenced both pre-impact responses, such as evacuation, and post-event recovery.⁹

As climate change increases the probability of more frequent or more severe extreme weather events, vulnerability mapping is an important tool for preparing for and responding to health threats.

9.5 Research Needs

A number of research needs related to populations of concern have been identified. There are some limitations with current public health surveillance and monitoring of risk factors that impede the development of projections of vulnerability to climate change impacts. Obtaining detailed data on social, economic, and health factors that contribute to vulnerability is challenging, especially at the small spatial scales required for analyzing climate change impacts. Privacy concerns often limit the collection and use of personal health and socioeconomic data. Ultimately, data limitations determine the feasibility of developing alternative vulnerability indicators using existing data sources. The science requires comprehensive and standardized measures of vulnerability that combine data identification and collection with the development of appropriate vulnerability indices.

More comprehensive and robust projections of factors that contribute to population vulnerability would also enhance the value of predictive models. At present, there are only limited projections of health status of the U.S. population, and the U.S. Census no longer provides population projections at the state level. Projecting population vulnerability into the future, as well as the development of consensus storylines that characterize alternative socioeconomic scenarios, will facilitate more robust and useful assessments of future health impacts of climate change.

Future assessments can benefit from research activities that:

- improve understanding of the relative contributions and causal mechanisms of vulnerability factors (for example, genetic, physiological, social, behavioral) to risks of specific health impacts of climate change;

- investigate how available sources of data on population characteristics can be used to create valid indicators and help map vulnerability to the health impacts of climate change;
- understand how vulnerability to both medical and psychological health impacts of climate change affect cumulative stress and health status; and
- evaluate the efficacy of measures designed to enhance resilience and reduce the health impacts from climate change at the individual, institutional, and community levels.

Supporting Evidence

PROCESS FOR DEVELOPING CHAPTER

The chapter was developed through technical discussions of relevant evidence and expert deliberation by the report authors at several workshops, teleconferences, and email exchanges. The authors considered inputs and comments submitted by the public, the National Academies of Sciences, and Federal agencies. For additional information on the overall report process, see Appendices 2 and 3.

The author team identified a number of populations affected by climate change health impacts, including communities of color and low-income, immigrant, and limited English proficiency groups; Indigenous populations; children and pregnant women; older adults; certain occupational groups; persons with disabilities; and persons with chronic medical conditions. This list of populations was identified to reflect current understandings related to how the health of particular groups of people or particular places are affected by climate change in the United States. While not exhaustive, these populations of concern are those most commonly identified and discussed in reviews of climate change health impacts on vulnerable populations. In this chapter, the order of these populations is not prioritized. While there are other populations that may be threatened disproportionately by climate change, the authors focused the sections of this chapter on populations for which there is substantive literature. In addition to this chapter's summary of vulnerable populations, each of the health outcome chapters in the report includes discussion of populations of concern. Some populations may be covered more extensively in these other chapters; for instance, homeless populations are discussed in Chapter 8: Mental Health, as the literature on this population focuses primarily on mental health.

KEY FINDING TRACEABLE ACCOUNTS

Vulnerability Varies Over Time and Is Place-Specific

Key Finding 1: Across the United States, people and communities differ in their exposures, 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*].

Description of evidence base

There is strong evidence from multiple current epidemiological studies on climate-sensitive health outcomes in the United States that health impacts will differ by location, pathways of exposure, underlying susceptibility, and adaptive capacity. The literature consistently finds that these disparities in health impacts will largely result

from differences in the distribution of individual attributes in a population that confers vulnerability (such as age, socioeconomic status, and race), attributes of place that reduce or amplify exposure (such as floodplain, coastal zone, and urban heat island), and the resilience of public health infrastructure.

Across multiple studies, the following factors are consistently identified that contribute to exposure: occupation,¹¹ time spent in risk-prone locations,^{12, 13, 14} displacement by weather extremes,⁶⁴ economic status,^{15, 16} condition of infrastructure,^{17, 18} and compromised mobility, cognitive function, and other mental or behavioral factors.¹⁹

There is consensus within the scientific literature that biologic sensitivity and adaptive capacity are tied to many of the same factors that contribute to exposures, and that all of these factors can change across time and life stage.^{12, 20, 21}

There is also strong evidence from multiple studies that social and economic factors affect disparities in the prevalence of chronic medical conditions that aggravate biological sensitivity.^{22, 23}

Major uncertainties

Understanding how exposure, sensitivity, and adaptive capacity change over time and location for specific populations of concern is challenging, particularly when attempting to project impacts of climate change on health across long time frames (such as in the year 2100, a year for which climate projections often estimate impacts) or vast geographic areas. Uncertainties remain with respect to the underlying social determinants of health, public health interventions or outreach, adaptation options, and climate impacts at fine local scales.

Assessment of confidence and likelihood based on evidence

Based on the evidence presented in the peer-reviewed literature, there is **very high confidence** that climate change impacts on health will vary across place and time, as demonstrated by the complex factors driving vulnerability. Many qualitative and quantitative studies have been published with consistent findings and strong consensus that the impacts of climate change on human health will vary according to differential exposure, sensitivity, and adaptive capacity, which change over time and across places. These conclusions are well-documented and supported by high-quality evidence from multiple sources.

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.

Description of evidence base

There is strong, consistent evidence from multiple studies that children have inherent sensitivities to climate-related health impacts. There are multiple, high-quality studies concerning the impact of changes in ground-level ozone, particulate matter, and aeroallergens on increases in childhood asthma episodes and other adverse respiratory effects in children.^{151, 152, 153, 156} In addition, the literature supports a finding that children are vulnerable to waterborne pathogens in drinking water and through exposures while swimming. There is a positive and statistically significant association between heavy rain and emergency department visits for children with gastrointestinal illness, though evidence comes from regional studies and is not at the national scale.^{159, 160} The science also supports a finding that children's mental health is affected by exposures to traumatic weather events, which can undermine cognitive development and contribute to psychiatric disorders.^{149, 150}

There is also strong, consistent evidence from multiple studies that older adults have inherent sensitivities to climate-related health impacts. In particular, exposure to extreme ambient temperature is an important determinant of health in older adults^{24, 203} and has been associated with increased hospital admissions for cardiovascular, respiratory, and metabolic disorders.^{26, 33} In addition, older adults are particularly affected by extreme weather events that compromise the availability and safety of food and water supplies; interrupt communications, utilities, and emergency services; and destroy or damage homes and the built environment.^{209, 210, 211, 226} Some functional and mobility impairments make older adults less able to evacuate when necessary.^{231, 301}

Major uncertainties

There is less information with which to quantify climate-related impacts on children and older adults at a national level given limited data availability. Some studies of age-related vulnerability have limited geographic scope or focus on single events in particular locations. Nevertheless, multiple factors, all with some degree of uncertainty, converge to determine climate-related vulnerability across age groups.

Assessment of confidence and likelihood based on evidence

Based on the evidence presented in the peer-reviewed literature, there is **high confidence** that a wide range of health effects exacerbated by climate change will be experienced by vulnerable age groups, especially young children and older adults. Both qualitative and quantitative studies have been published about the effects of age or life stage on vulnerability to health impacts, and that evidence is consistent and of good quality.

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

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*].

Description of evidence base

The literature is consistent and the results are compelling that social determinants of health, such as those related to socioeconomic factors and health disparities, will contribute to the nature and extent of vulnerability and health effects due to climate change. The following factors illustrate the depth of the literature supporting the conclusions above regarding the relationship between climate change health threats, vulnerability (comprised of exposure, sensitivity, and adaptive capacity), and social determinants of health:

- **Occupation:** where workers are at risk due to their place of employment or the nature of their duties.¹¹
- **Time spent in risk-prone locations:** There is an extensive literature base and broad consensus to support a finding that locations that experience greater risks include urban heat islands where exposed populations are likely to have limited adaptive capacity due to poor housing conditions, and inability to use or to afford air conditioning.^{15, 24, 26, 34, 35, 38, 55, 56, 57}
- **Economic status:** In the literature, a significant relationship has been observed that links people living in poverty with being less likely to have adequate resources to prepare for or respond to extreme events or to access and afford necessary health or supportive services to cope with climate-related health impacts.^{39, 42, 43, 44, 45, 46}
- **Condition of infrastructure:** Deteriorating infrastructure exposes people to increased health risks. The literature is consistent and of good quality to support a finding that persons who evacuate may be hampered by damage to transportation, utilities, and medical or communication facilities and by a lack of safe food or drinking water supplies.^{12, 139, 226, 229}
- **Disparities in health conditions:** Health disparities contribute to the sensitivity of people to climate change. Numerous studies indicate increased sensitivity and health risk for people with chronic or preexisting medical or psychological illnesses, people of certain age or stage of life; and people with compromised mobility or cognitive functioning.^{143, 289, 290} Social determinants of health contributing to disparities in rates of these conditions increase sensitivity of affected populations.^{32, 206, 289, 290}

Health risks and vulnerability may increase in locations or instances where combinations of social determinants of health that amplify health threats occur simultaneously or close in time or space.^{6, 7} For example, people with limited

economic resources living in areas with deteriorating infrastructure are more likely to experience disproportionate impacts and are less able to recover following extreme events,^{8,9} increasing their vulnerability to climate-related health effects.

Major uncertainties

A wide range of non-climate factors are expected to interact with climate change health impacts to determine population vulnerability, all with some degree of uncertainty. The extent to which social determinants of health individually and collectively affect the different components of vulnerability is, in many cases, not well understood and not readily amenable to measurement or quantification. Assessing the extent and nature of non-climate impacts as compared to impacts related to climate change is limited by data availability. Many studies of climate change vulnerability have limited geographic scope or focus on single events in particular locations, which makes drawing national-level conclusions more challenging.

Assessment of confidence and likelihood based on evidence

Based on the evidence presented in the peer-reviewed literature, there is **high confidence** that climate change threatens the health of people and communities by affecting exposure, sensitivity, and adaptive capacity. This conclusion takes into account the consistent evidence presented in multiple studies regarding the causes of vulnerability to climate-related health effects and the role of social determinants of health. There is **high confidence** based on many peer-reviewed studies that social determinants of health, such as those related to socioeconomic factors and health disparities, may amplify, moderate, or otherwise influence climate-related health effects across populations of concern, and the evidence presented is of good quality, consistent, and compelling.

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*].

Description of evidence base

Over the past decade, the literature on the use of GIS in a public health and vulnerability context has been steadily growing. Multiple studies provide strong, consistent evidence that spatial-analytic tools help facilitate analyses that link together spatially resolved representations of census data, data on the determinants of health (social, environmental, preexisting health conditions), measures of adaptive capacity (such as health care accessibility), and environmental data for the identification of at-risk populations.^{4, 10, 294, 295, 296, 297}

Similarly, the more recent additions to the literature indicate that demographic and environmental data can be integrated

to create an index that allows for analysis of the factors contributing to social vulnerability in a given geographic area.^{292, 294} Multiple studies conclude that spatial mapping that identifies factors associated with relative vulnerability is an important step in developing prevention strategies or determining where to focus or position health or emergency response resources.^{298, 299, 300} Fewer studies explicitly focus on vulnerability mapping in a climate change context, with the notable exception of the case study of heat-related vulnerability in Georgia.²⁹⁴

Major uncertainties

Multiple factors, all with some degree of uncertainty, determine geographic vulnerability to the health impacts of climate change. Although the literature indicates that mapping tools and vulnerability indices are useful in characterizing geographically based exposures, geocoded health data (particularly those data relevant to an analysis of climate change vulnerability) are not always available in some locations of interest. In addition, the extent of uncertainty increases at smaller spatial scales, which is typically the scale most relevant for targeting vulnerable communities. For instance, mental health outcome data are particularly challenging to obtain and geocode, partly because the majority of cases are underdiagnosed or underreported (see Ch. 8: Mental Health).

Assessment of confidence and likelihood based on evidence

Based on the evidence presented in the peer-reviewed literature, there is **high confidence** that geographic data used in mapping tools and vulnerability indices can help to identify where and for whom climate health risks are greatest. A number of published studies provide consistent and good quality evidence to support a finding regarding the utility of mapping tools and vulnerability indices in a public health context, but methods are still emerging to support the application of these tools in the context of climate change. Overall, evidence is strong that mapping tools and vulnerability indices can help to identify at-risk locations and populations for whom climate health risks are greatest. As the state of the science continues to evolve, substantial improvements in mapping and spatial analytic tools and methodologies are expected that will allow researchers to predict, for a certain geographic area, the probability that human health impacts will occur across time.

DOCUMENTING UNCERTAINTY

This assessment relies on two metrics to communicate the degree of certainty in Key Findings. See Appendix 4: Documenting Uncertainty for more on assessments of likelihood and confidence.

Confidence Level	Likelihood
Very High	Very Likely
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	≥ 9 in 10
High	Likely
Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	≥ 2 in 3
Medium	As Likely As Not
Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	≈ 1 in 2
Low	Unlikely
Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts	≤ 1 in 3
	Very Unlikely
	≤ 1 in 10

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