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Written Testimony of

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Full Committee Hearing
on:
The State of Climate Science

before the
United States House Committee on Science, Space, and Technology

February 13, 2019

Good morning, Chairwoman Johnson and Ranking Member Lucas. Thank you for the opportunity to speak with the full committee today about the current understanding of the health risks of climate change. My name is Kristie L. Ebi; I am the Director of the Center for Health and the Global Environment (CHanGE) and the Rohm and Hass Endowed Professor in Public Health Sciences at the University of Washington School of Public Health. Climate change is affecting the health of Americans today and will affect our health and our public health and healthcare infrastructure in the future. This is an issue of critical national importance. Therefore, it is timely and appropriate for Congress to understand these challenges so that effective actions can be taken to protect and promote the health of Americans now and in the future.

In summary, the evidence is clear: climate change is adversely affecting the health of Americans, with the impacts projected to increase with each additional unit of warming, depending on the rapidity and extent of greenhouse gas emission reductions. Climate change has warmed the world by roughly 1.8°F since preindustrial times, with the rate of warming increasing significantly since the 1970s[1]. This warming is heating the land and oceans, melting snow and ice, increasing the frequency and severity of extreme weather events, and raising sea levels. All of these have potential implications for our health and well-being.

There are immediate actions that could increase preparedness for effectively managing these risks, including the risks to our healthcare infrastructure. Further, nearly all mitigation policies to reduce greenhouse gas emissions have benefits for health. The costs associated with those benefits, as measured by reductions in premature mortality and avoided hospitalizations, are about the same as the cost of the policies.

The following sections (1) summarize the health risks of a changing climate in the United States, including the risks for our health care infrastructure, and describe populations at particular risk; (2) show how adaptation can protect and promote population health today and in the future; and

[1] https://science2017.globalchange.gov/

(3) discuss the significant health co-benefits of mitigation policies and technologies. My testimony draws primarily from the 4th U.S. National Climate Assessment (NCA4)[2] and the Lancet Countdown Brief for the United States[3]. Other recent publications and assessments of the health risks of climate change include the Lancet Countdown[4]; the Intergovernmental Panel on Climate Change Special Report on Warming of 1.5°C[5]; and a publication in the New England Journal of Medicine on the imperative for climate action to protect health[6].

Health risks of a changing climate in the United States

There is an increasing body of evidence highlighting the damaging effects of climate change on human health and health care infrastructure. This research was assessed in the NCA4 in the chapter on human health and in the sectoral chapters, and the *Lancet* Countdown Brief for the United States. These reports, and the underlying science on which they are based, concluded that climate change harms health and health care infrastructure. A key message from the NCA4 was:

> *The health and well-being of Americans are already affected by climate change, with the adverse health consequences projected to worsen with additional climate change. Climate change affects human health by altering exposures to heat waves, floods, droughts, and other extreme events; vector-, food- and waterborne infectious diseases; changes in the quality and safety of air, food, and water; and stresses to mental health and well-being.*

A wide range of health outcomes can be affected by weather, climate variability, and climate change (Figure 1). Scientists have explored the many different pathways linking our changing climate with human health. For example, recent warming has lengthened the pollen season in the Midwest anywhere from 2-4 weeks, exacerbating allergic rhinitis and allergic asthma[7]. Additional warming is likely to further lengthen the season, substantially reducing the quality of life for those with these conditions.

The adverse health effects attributed to climate change have many potential economic and social costs, including medical expenses, caregiving services, lost productivity, as well as costs that are harder to quantify, such as those associated with pain, suffering, inconvenience, or reduced enjoyment of leisure activities[2]. These health burdens are typically borne by the affected individual and by family, friends, employers, communities, and insurance or assistance programs.

A recent research project I conducted with colleagues summarized the 109 published projections of the health risks associated with temperature extremes and occupational heat stress, air quality,

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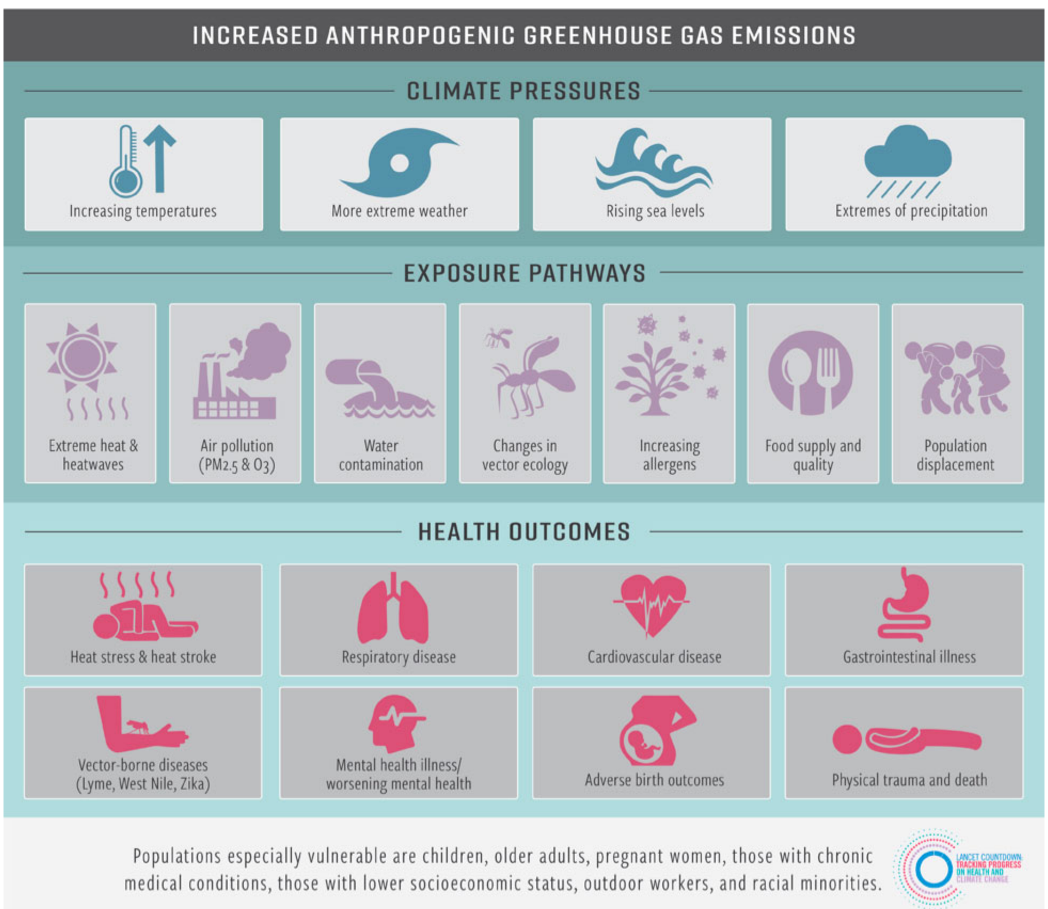
[2] https://nca2018.globalchange.gov/chapter/14/
[3] http://www.lancetcountdown.org/media/1426/2018-lancet-countdown-policy-brief-usa.pdf
[4] http://www.lancetcountdown.org/the-report/
[5] https://www.ipcc.ch/sr15/
[6] Haines A, Ebi K. The imperative for climate action to protect health. *New England Journal of Medicine* 2019;380:263-273.
[7] Ziska L, Knowlton K, Rogers C, et al. Recent warming by latitude associated with increased length of ragweed pollen season in central North America. *Proceedings of the National Academy of Sciences* 2011;108(10): 4248.

undernutrition, and vector-borne diseases to estimate how these risks would differ at increases in warming of 1.5°C, 2°C, and higher[8]. Risks were higher at 2°C for adverse health consequences associated with exposures to high ambient temperatures, ground-level ozone, and undernutrition, with regional variations. Risks for vector-borne diseases could increase or decrease with higher global mean temperatures, depending on regional climate responses and disease ecology. The Intergovernmental Panel on Climate Change Special Report on Warming of 1.5°C concluded that[5]:

> Any increase in global warming is projected to affect human health, with primarily negative consequences (*high confidence*). Lower risks are projected at 1.5°C than at 2°C for heat-related morbidity and mortality (*very high confidence*) and for ozone-related mortality if emissions needed for ozone formation remain high (*high confidence)*. Urban heat islands often amplify the impacts of heatwaves in cities (*high confidence*). Risks from some vector-borne diseases, such as malaria and dengue fever, are projected to increase with warming from 1.5°C to 2°C, including potential shifts in their geographic range (*high confidence*).

Figure 1: Summary of the health risks of climate change in the United States



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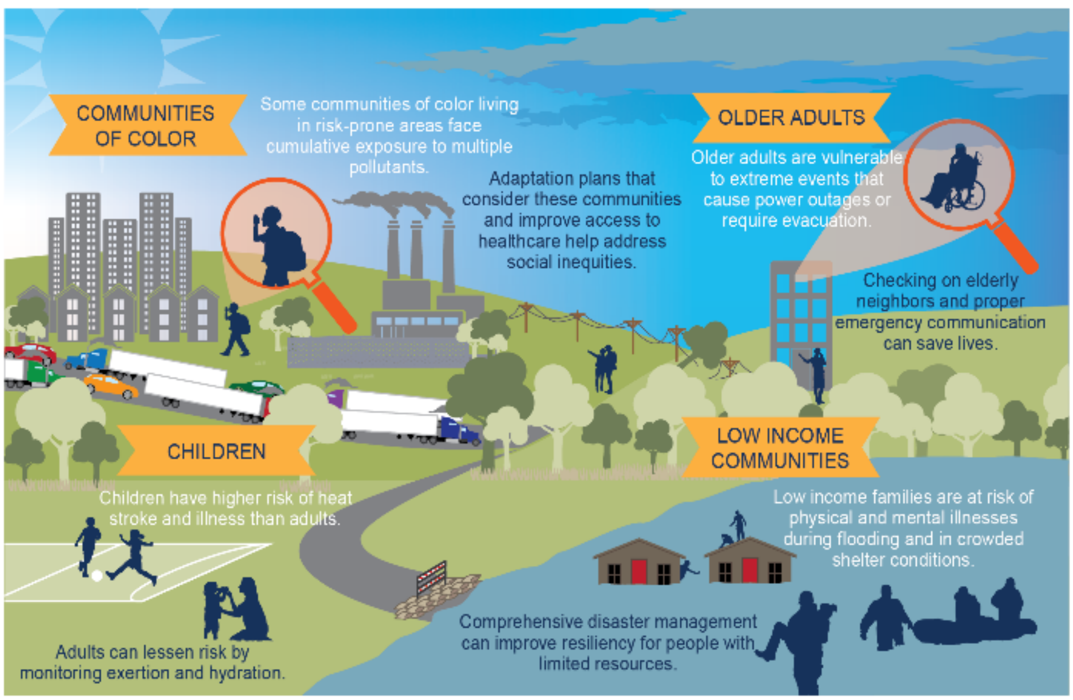
[8] Ebi KL, Hasegawa T, Hayes K, Monaghan A, Paz S, Berry P. Health risks of warming of 1.5° C,. 2° C, and higher, above pre-industrial temperatures. *Environmental Research Letters* 2018;13:063007.

Another key message from the NCA4 was that although everyone is exposed to a changing climate, exposure and resilience capacity vary across the population (Figure 2):

> *People and communities are differentially exposed to hazards and disproportionately affected by climate-related health risks. Populations experiencing greater health risks include children, older adults, low-income communities, and some communities of color.*

Figure 2 shows examples of populations at higher risk of exposure to adverse climate-related health threats along with adaptation measures that can help address disproportionate impacts. When considering the full range of threats from climate change as well as other environmental exposures, these groups are among the most exposed, most sensitive, and have the least individual and community resources to prepare for and respond to health threats. White text indicates the risks faced by those communities, while dark text indicates actions that can be taken to reduce those risks.

Figure 2: Exposure and resilience vary across populations and communities [2]



Low-income communities and some communities of color are often already overburdened with poor environmental conditions and are disproportionately affected by, and less resilient to, climate-sensitive health outcomes[2]. Climate change is expected to compound existing health issues in Native American and Alaska Native communities, partly due to the loss of traditional foods and practices, the mental stress from permanent community displacement, increased injuries from lack of permafrost, storm damage and flooding, smoke inhalation, damage to water and sanitation systems, decreased food security, and new infectious diseases

Vulnerability is typically higher in communities with less access to information, resources, institutions, and other factors to prepare for and avoid the health risks of climate change. Some of these communities include poor people in high-income regions, minority groups, women, pregnant women, those experiencing discrimination, children under five, persons with physical and mental illness, persons with physical and cognitive disabilities, the homeless, those living alone, Indigenous people, people displaced because of weather and climate, the socially isolated, poorly planned communities, the disenfranchised, those with less access to healthcare, the uninsured and underinsured, those living in inadequate housing, and those with limited financial resources to rebound from disasters[2].

Summary of selected health risks

This section summarizes some of the most well-understood health risks associated with climate change and their effects across the United States.

Extreme heat*:* Summers are starting earlier, lasting longer, and are on average hotter, with temperature records being broken regularly. The average summer temperature in 2016 was 2.2°F greater than the 1986-2005 average, resulting in 12.3 million more Americans exposed to extreme heat that year[3]. Thus, it should not be surprising that extreme heat is the leading cause of weather-related deaths in the U.S.

Exposure to extreme heat can lead to heat exhaustion, life threatening heat stroke, and exacerbate chronic lung, heart, and kidney diseases. Further, emerging evidence suggests that hotter temperatures can cause pregnancy complications, worsen mental health conditions, and increase suicides, amongst other risks[3]. One estimate projected that by the year 2050, approximately 3,400 more Americans could die annually from heat–related causes[9].

Individuals more sensitive to exposure to extreme heat include children, pregnant women, outdoor workers, older adults, those who are chronically ill, and low-income families. Health risks may be higher earlier in the summer season when people are less accustomed to experiencing higher temperatures. Here are some of the facts:

- At least 729 children died from heatstroke across the country after being left in hot cars between 1990 and 2014[10].
- Studies in the United States have linked extreme heat exposure to preterm births and low birth weights[11].

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[9] U.S. Environmental Protection Agency. Multi-Model Framework for Quantitative Sectoral Impacts Analysis: A Technical Report for the Fourth National Climate Assessment [Internet]. Washington DC; 2017. Available from: https://cfpub.epa.gov/si/si_public_record_Report.cfm?Lab=OAP&dirEntryId=335095

[10] Zonfrillo MR, Ramsay ML, Fennell JE, Andreasen A. Unintentional non-traffic injury and fatal events: Threats to children in and around vehicles. Traffic injury prevention 2018;19(2), 184-188.

[11] Kuehn L., McCormick,S. Heat exposure and maternal health in the face of climate change. International journal of environmental research and public health Kuehn, L., & McCormick, S. (2017). Heat exposure and maternal health in the face of climate change. International journal of environmental research and public health, 14(8), 853.2017;14(8), 853.

- Outdoor workers in the agriculture and construction industries are disproportionately vulnerable to heat-related illness. In Maricopa County, Arizona, 115 men in these industries died due to heat-related causes between 2002-2009, comprising 35% of all male deaths from heat-related causes[12].

However, heat-related deaths can be prevented. Strategies to accomplish this include heatwave early warning and response systems, which provide advanced and timely information to individuals about the risks of thermal extremes through television, radio, text messaging, and other forms of communication, empowering individuals and communities to make smart choices to protect themselves. Other options include individual acclimatization (the process of adjusting to higher temperatures) and protective measures, such as air conditioning at home, cooling shelters, green space in the neighborhood, and resilient power grids to avoid power outages during extreme weather events[2].

Communities across the United States should learn from past heat-related tragedies to protect populations from future extreme heat events. The City of Philadelphia, PA provides an example. In July 1993, a devastating heat wave hit the Mid-Atlantic region, resulting in 118 excess deaths in Philadelphia[13]. Since that tragic event, the City of Philadelphia took proactive measures to prevent a repeat occurrence, despite rising summer temperatures. The City developed a system triggered when the National Weather Service issues an Excessive Heat Warning. The Philadelphia Department of Public Health (PDPH) Excessive Heat Public Safety Plan uses a variety of communication tools, including press releases, social media, and the PDPH website to inform the public about heat-related dangers. An emergency phone line staffed with public health nurses is also opened, as are cooling centers to allow individuals without access to cooling to seek relief. This comprehensive heat early warning system provides frequent and consistent messaging to the public, warning of the dangers of extreme temperatures and providing information on how to stay cool. Since 1993, heat-related deaths in Philadelphia have fallen dramatically, with annual deaths now in the low single digits.

Analyses of hospital admissions, emergency room visits, and emergency medical services calls show that hot days also are associated with an increase in heat-related illnesses, including cardiovascular and respiratory complications, renal failure, electrolyte imbalance, kidney stones, negative impacts on fetal health, and preterm birth[2]. Risks vary across regions. The healthcare costs from just one heatwave in California were estimated at $179 million[14].These costs could be reduced substantially with investments in heatwave early warning systems and other preventive measures, saving money and lives.

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[12] Petitti DB, Harlan SL, Chowell-Puente G, Ruddell D. Occupation and Environmental Heat-Associated Deaths in Maricopa County, Arizona: A Case-Control Study. PLoS ONE 2013;8(5): e62596. https://doi.org/10.1371/journal.pone.0062596

[13] Kalkstein LS, Sheridan SC, Kalkstein AJ. Heat/Health Warning Systems: Development, Implementation, and Intervention Activities. In: Ebi K.L., Burton I., McGregor G.R. (eds) *Biometeorology for Adaptation to Climate Variability and Change.* Biometeorology, vol 1. 2009. Springer, Dordrecht

[14] Knowlton K, Rotkin-Ellman M, Geballe L, Max W, Solomon GM. Six Climate Change–Related Events In The United States Accounted For About $14 Billion In Lost Lives And Health Costs. *Health Affairs* 2011 Nov 2 [cited 2018 Nov 7];30(11):2167–76. Available from: http://www.healthaffairs.org/doi/10.1377/hlthaff.2011.0229

Heatwave early warning systems established in large cities across America informed the development of the National Integrated Heat Health Information System (NIHHIS) that provides an online portal of information and resources to help communities understand prepare for the health impacts of extreme heat[15]. NIHHIS is an interagency partnership developed by the Centers for Disease Control and Prevention, the National Oceanic and Atmospheric Administration, and domestic and international partners, with the goals of building understanding of the problem of extreme heat; defining demand for climate services that enhance societal resilience; developing science-based products and services from a sustained climate science research program; and improving capacity, communication, and societal understanding of the problem in order to reduce morbidity and mortality due to extreme heat. Communities, particularly in smaller cities and rural areas, generally need human and financial resources to design and implement heatwave early warning systems that take into account local vulnerabilities and capacities.

Extreme Weather and Climate Events: Extreme weather and climate events, such as floods, droughts, and wildfires, are increasing with climate change, threatening health and healthcare facilities. Hurricanes also cause significant damage. The health, well-being, and security of populations are significantly and increasingly affected by extreme weather and climate events. Death, physical injury, and increased risk of disease and mental health impacts can result from climate-related disasters. The indirect consequences can include substantial and long-lasting impacts on health systems, population health, and livelihoods. These events can destroy health care infrastructure, damage medical equipment and supplies, result in fewer health personnel to provide care, and disrupt health-related services (e.g. water and sanitation facilities), leading to a reduced capacity to meet public health needs[2,3]. Loss of livelihoods (e.g. lower crop yields) and population displacement can also adversely affect, for example, nutritional status and mental illness.

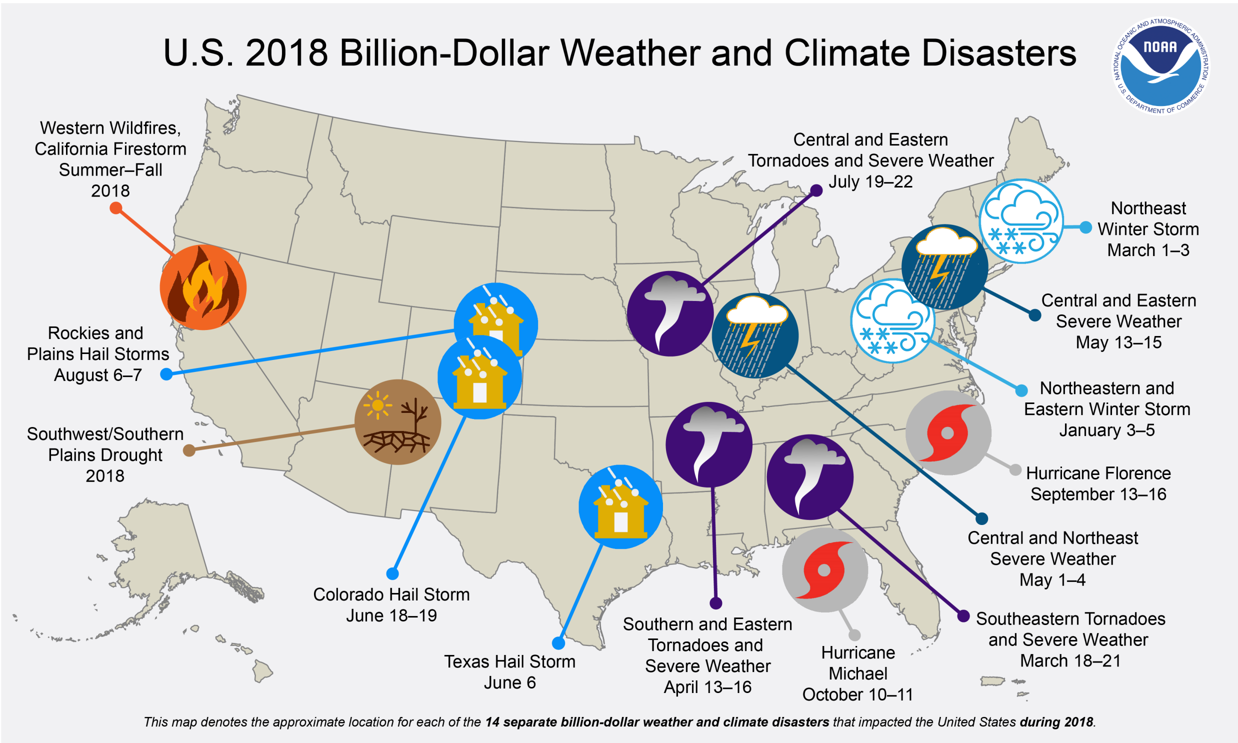
One example is the health impacts of drought and periods of unusually dry weather. In late 2015, California was in the fourth year of its most severe drought since becoming a state, with 63 emergency proclamations declared in cities, counties, tribal governments, and special districts[2]. Households in Tulare and Mariposa counties reported a range of drought-related health impacts, including increased dust leading to allergies, asthma, and other respiratory issues and acute stress and diminished peace of mind. These health impacts were not evenly distributed, with more negative physical and mental health impacts reported when drought negatively affected household property and finances.

Extreme weather and climate events are having an increasingly devastating impact on Americans in terms of lives lost, lives affected, and economic cost. In 2017 alone there were 16 billion-dollar disasters in the U.S. that together cost about $306 billion dollars[16]. The official death toll was estimated at 3,278, although the actual total was likely much higher. During the same year, 23 events (floods, storms, wildfires) affected approximately 866,835 individuals, and the homes of 109,108 individuals were destroyed[3]. The U.S. had 14 billion-dollar disasters in 2018, killing at least 247 people, and costing the nation an estimated $91 million (Figure 3). Most of that

[15] https://toolkit.climate.gov/tool/national-integrated-heat-health-information-system-nihhis
[16] https://www.ncdc.noaa.gov/billions/

damage, about $73 billion, was attributable to three events: Hurricanes Michael and Florence and the collection of wildfires that raged across the West. Since 1980, overall damages from 219 weather and climate billion-dollar disasters in the U.S. exceeded $1.6 trillion., with over 10,000 deaths.

Figure 3: U.S. 2018 billion-dollar weather and climate disasters



The 2018 wildfire season in California was the deadliest and most destructive on record, with 8,527 fires burning an area of nearly 1.9 million acres, the largest amount burned in a fire season, and about 100 fatalities. In addition, large populations were exposed to gases and fine particulates that can harm the heart and lungs; at times, the air quality in parts of California were unhealth for all to breathe. Wildfires are expected to become more common as the climate continues to change, which means more Americans could be exposed and adversely affected.

The impacts of an extreme weather or climate event are often not confined to the directly affected area. For example, wildfire smoke can affect air quality over multiple states. Individuals displaced by hurricanes or floods may move to other regions to seek shelter and access health care.

Children, older adults, low-income communities, some communities of color, and those experiencing discrimination are disproportionately affected by extreme weather and climate events, partially because they are often excluded in planning processes. Other populations that could experience increased sensitivity to extreme weather and climate events include outdoor workers and communities disproportionately burdened by poor environmental quality.

In addition to the direct harms on human health, extreme weather and climate events have the potential to adversely affect the operation of hospitals and other critical healthcare physical infrastructure. During Hurricane Harvey, hospitals in Houston, Texas were challenged to provide essential medical services to their patients. According to Darrel Pile, chief executive of the Southeast Texas Regional Advisory Council, Harvey "challenged every plan we've written, every resource, every piece of inventory…it was just unimaginable[17]." Despite the challenges faced during and after Harvey, the impacts on healthcare could have been far worse, had health systems not had plans in place to deal with an event of this magnitude. Such plans included sealing flood-prone areas and making provisions for extra personnel and supplies. As climate change increases the risks of extreme weather and climate events that can disrupt healthcare operations, additional planning will be needed to ensure continuity of care even during meteorological conditions thought unimaginable a decade ago.

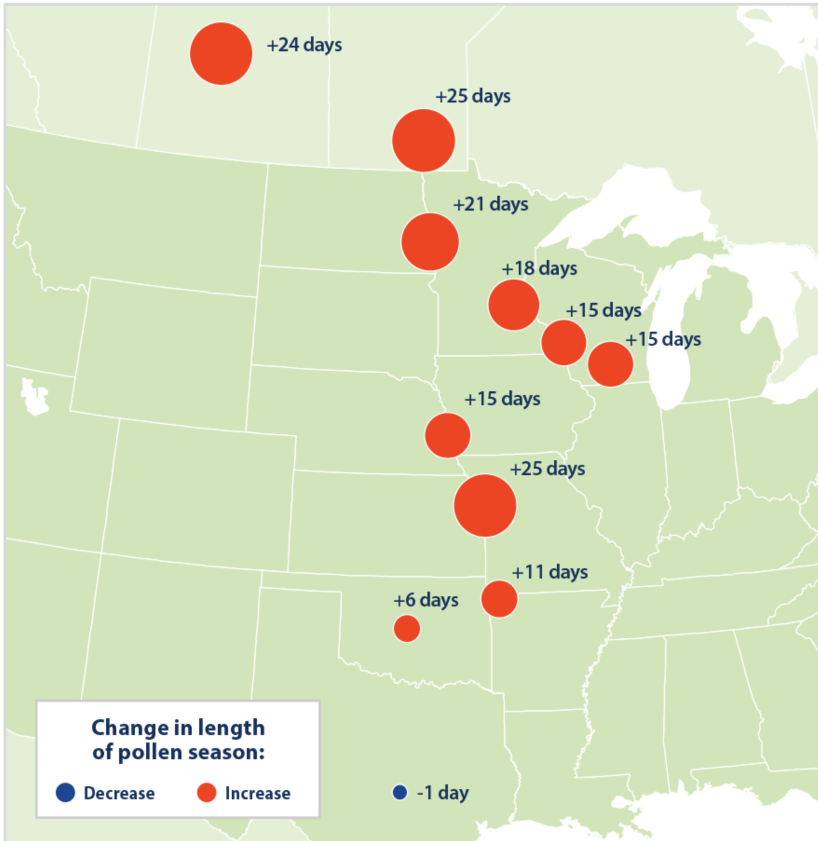
Air quality: Poor air quality causes a host of health complications, including premature mortality, exacerbations of chronic obstructive pulmonary disease, asthma, and allergies. Climate change is decreasing air quality by increasing concentrations of ground-level ozone that harms the lungs and can cause early death. Long-term exposure to ozone is linked to aggravation of asthma and is likely one cause of asthma development. Long-term exposures to higher concentrations of ozone may also be linked to permanent lung damage, such as abnormal lung development in children.

Earlier springs, warmer temperatures, precipitation changes, and higher carbon dioxide concentrations can increase exposure to pollen allergens that can be especially problematic to those with hay fever and asthma. Warmer spring temperatures cause some plants to start producing pollen earlier, while warmer fall temperatures extend the growing season for other plants, such as ragweed[18]. Figure 4 shows changes in the ragweed pollen season from 1995-2015. While air quality across the U.S. improved since 1988, it has been deteriorating in western states because of wildfires.

People most at risk from poorer air quality include people with asthma, children, older adults, and people who are active outdoors, especially outdoor workers. In addition, people with certain genetic characteristics, and people with reduced intake of certain nutrients, such as vitamins C and E, are at greater risk from ozone exposure[19].

[17] https://www.washingtonpost.com/national/health-science/some-hospitals-evacuated-but-houstons-vaunted-medical-world-mostly-withstands-harvey/2017/08/30/2e9e5a2c-8d90-11e7-84c0-02cc069f2c37_story.html?utm_term=.2c451810a9db
[18] https://www.epa.gov/climate-indicators/climate-change-indicators-ragweed-pollen-season
[19] https://www.epa.gov/arc-x/climate-adaptation-ground-level-ozone-and-health

Figure 4: Changes in the ragweed pollen season, 1995-2015



This figure shows how the length of ragweed pollen season changed at 11 locations in the central United States and Canada between 1995 and 2015. Red circles represent a longer pollen season; the blue circle represents a shorter season. Larger circles indicate larger changes. Source: EPA

Infectious diseases: Multiple infectious diseases are transmitted by mosquitoes, ticks, and fleas (e.g. vectors), including Lyme disease, dengue fever, and West Nile virus. The number of cases of climate-sensitive infectious diseases tripled between 2004-2016, with over 96,000 documented cases in 2016[3]. Areas not accustomed to particular infectious diseases are reporting cases for the first time. For instance, in my home of Western Washington, public health officials identified the first locally-transmitted case of West Nile Virus, a likely harbinger of trends to come as summers continue to warm in the Pacific Northwest.

Climate change is expected to alter the geographic range, seasonal distribution, and abundance of disease vectors, exposing more people in North America to ticks that carry Lyme disease or other bacterial and viral agents, and to mosquitoes that transmit West Nile and other viral diseases[2]. In the absence of adaptation, exposure to the mosquito *Aedes aegypti* that can transmit dengue, Zika, chikungunya, and yellow fever viruses, is projected to increase by the end of the century due to climatic, demographic, and socioeconomic changes, with some of the largest increases projected to occur in North America. Similarly, changes in temperature may influence the distribution and abundance of tick species that transmit common pathogens. At the same time, very high temperatures may reduce transmission risk for some diseases.

Changing weather patterns interact with other factors, including how pathogens adapt and change, changing ecosystems and land use, demographics, human behavior, and the status of public health infrastructure and management. Economic development may substantially reduce transmission risk by reducing contacts with vector populations.

Outbreaks occurring in other countries can impact U.S. populations and military personnel living abroad and can sometimes affect the United States[2]. For example, the 2015–16 El Niño, one of the strongest on record, may have contributed to the 2014–16 Zika epidemic in the Americas. Warmer conditions may have facilitated expansion of the geographic range of mosquito populations and increased their capacity to transmit Zika virus. Zika virus can cause a wide range of symptoms, including fever, rash, and headaches, as well as birth defects. The outbreak began in South America and spread to areas with mosquitoes capable of transmitting the virus, including Puerto Rico, the U.S. Virgin Islands, Florida, and Texas.

Effective public health strategies can reduce the dangers associated with the expansion of the geographic range of climate-sensitive infectious diseases. As diseases move into new areas, public health messaging on appropriate prevention strategies must be adopted in order to prevent uncontrolled outbreaks. Similarly, continuing education for healthcare professionals should emphasize the potential health hazards associated with climate change. Many medical staff may be faced with conditions never encountered heretofore in their careers and must be prepared to treat them appropriately.

Additionally, it is possible to forecast where and when the associated diseases could occur based on understanding the environmental determinants of these vectors and the pathogens they can carry[20]. This vital information can provide up to months lead time for public health practitioners to prepare for and effectively respond to outbreaks.

Water-related illnesses and deaths: The growth rate of several important human pathogens that can contaminate water depend on the temperature of the water. Because there are thresholds for of how many organisms are required for disease to occur, increasing water temperatures associated with climate change are projected to alter the seasonality of growth and the geographic range of harmful algae and coastal pathogens[3]. Further, runoff from more frequent and intense rainfall is projected to increasingly compromise recreational waters and sources of drinking water through increased introductions of pathogens and toxic algal blooms. Projected increases in extreme precipitation and flooding, combined with inadequate water and sewer infrastructure, can contribute to viral and bacterial contamination from combined sewage overflows and a lack of access to potable drinking water, increasing exposure to pathogens that can cause gastrointestinal illnesses.

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[20] Morin CW, Semenza JC, Trtanj JM, Glass GE, Boyer C, Ebi KL. Unexplored Opportunities: Use of Climate-and Weather-Driven Early Warning Systems to Reduce the Burden of Infectious Diseases. *Current Environmental Health Reports* 2018: p. 1-9; https://doi.org/10.1007/s40572-018-0221-0

There is robust scientific understanding of the relationship between warmer water temperatures associated with longer summers and the growth of bacteria called *Vibrios* that can cause diarrheal illnesses, food poisoning, and skin infections. In the Northeast U.S., there was a 27% increase in the coastline area suitable for *Vibrios* in the 2010s vs the 1980s[3]. This means more Americans could be at risk through contact with the water or by eating contaminated shellfish. Increases in air temperatures and heatwaves are expected to increase temperature-sensitive marine pathogens such as *Vibrios*. Improving research and communication around the risks posed by *Vibrios* is essential to protecting human health as well as the viability of the shellfish industry that forms a critical component of many coastal and Native American communities.

The relationships between precipitation and temperature-driven transmission of waterborne diseases are complex and site-specific, with, for example, some areas finding increased numbers of cases associated with excessive rainfall and others finding stronger associations with drought. Heavy rainfall, flooding, and high temperatures are associated with increases in diarrheal disease and can increase other bacterial and parasitic infections such as leptospirosis and cryptosporidiosis.

Food security and nutrition: Climate change, including changes in some extreme weather and climate events, can adversely affect U.S. and global food security by, for example, altering exposures to certain pathogens and toxins (for example, *Salmonella* and *Campylobacter*), disrupting food availability, decreasing access to food, and increasing food prices[2]. Food quality also is expected to be affected by rising carbon dioxide concentrations that decrease dietary iron, zinc, protein, and other macro- and micronutrients in key staple crops such as wheat and rice. However, any impact on human health will depend on the many other drivers of global food security and factors such as food chain management, human behavior, and food safety governance.

Projected changes in carbon dioxide concentrations and climate change could diminish expected gains in global nutrition[2].

Mental health: Exposure to short-lived or prolonged weather- or climate-related events can result in mental health consequences, from stress and distress symptoms to clinical disorders, such as anxiety, depression, post-traumatic stress, and suicidality[2]. These mental health impacts can interact with other health, social, and environmental stressors to diminish an individual's well-being. Individuals whose households experienced a flood or risk of flood report higher levels of depression and anxiety, with these impacts possibly persisting for several years. Disasters present a heavy burden on the mental health of children when there is forced displacement from their home or a loss of family and community stability. Increased use of alcohol and tobacco are common following disasters as well as droughts. Higher temperatures can lead to an increase in aggressive behaviors, including homicide.

Groups potentially more vulnerable include the elderly, pregnant women, people with preexisting mental illness, the economically disadvantaged, tribal and Indigenous communities, and first responders. Social cohesion, good coping skills, and preemptive disaster planning are examples of adaptive measures that can help reduce the risk of prolonged psychological impacts.

Adaptation can protect and promote population health today and in the future

Targeted policies and programs are needed to protect vulnerable populations, and healthcare systems must become more resilient. The NCA4 concluded:

> *Proactive adaptation policies and programs reduce the risks and impacts from climate-sensitive health outcomes and from disruptions in healthcare services. Additional benefits to health arise from explicitly accounting for climate change risks in infrastructure planning and urban design.*

Individuals, communities, public health departments, healthcare facilities, organizations, and others are taking action to reduce health and social vulnerabilities to current climate change and to increase resilience to the risks projected in coming decades[2].

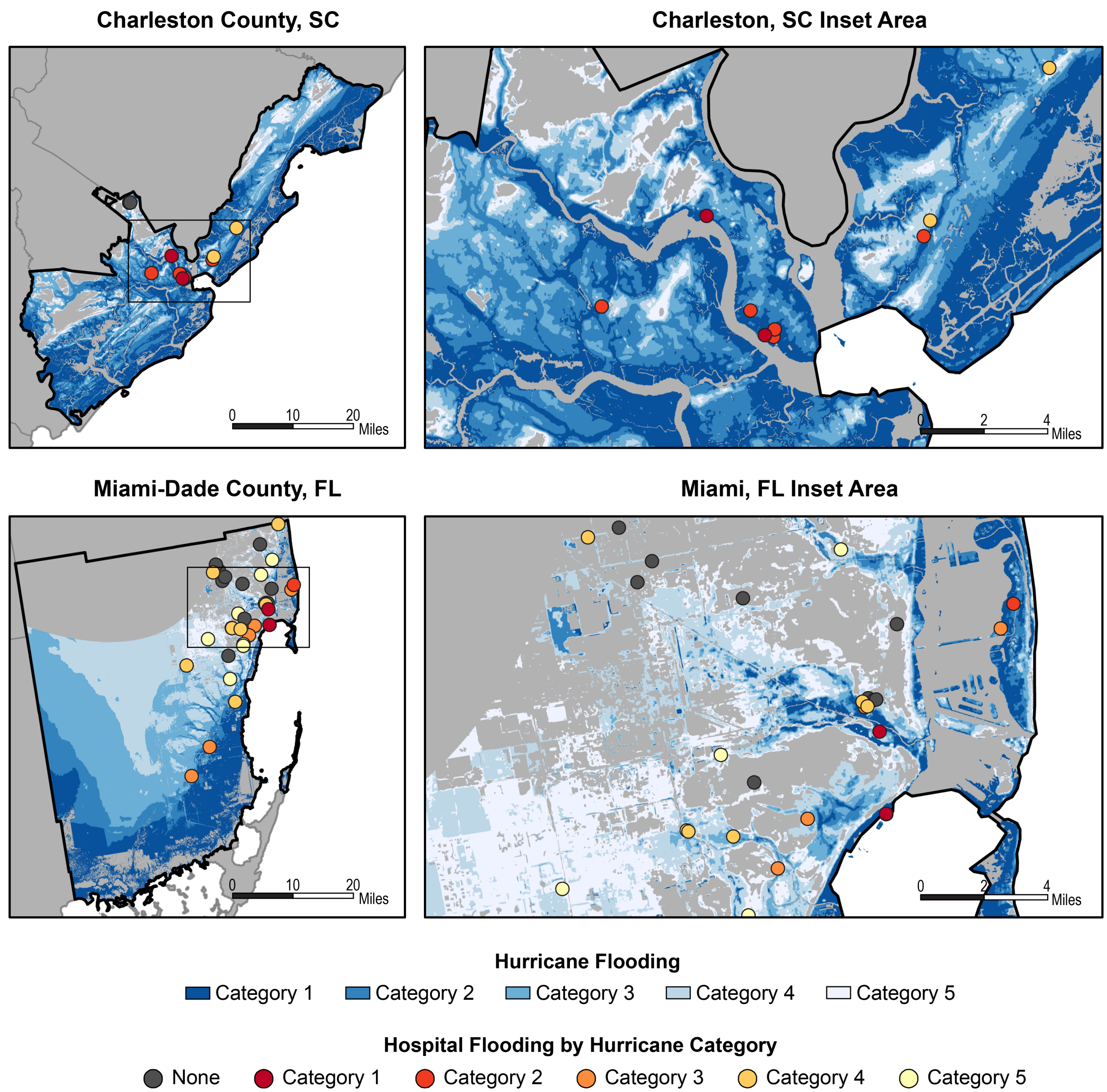
Examples of state-level adaptation actions include conducting vulnerability and adaptation assessments, developing comprehensive response plans (such as for extreme heat), climate-proofing healthcare infrastructure, and implementing integrated surveillance of climate-sensitive infectious disease that can incorporate short-term to seasonal forecasts (such as for Lyme disease or dengue fever)[2]. Incorporating climate projections into emergency preparedness and disaster risk management can increase preparedness for changing weather patterns.

Local efforts include altering urban design (for example, by using cool roofs, tree shades, and green walkways) and improving water management (for example, via desalination plants or watershed protection)[2]. These can provide health and social justice benefits, elicit neighborhood participation, and increase resilience for specific populations, such as outdoor workers.

Early warning and response systems can protect population health now and provide a basis for more effective adaptation to future climate[2]. Improvements in forecasting weather and climate conditions and in environmental observation systems, in combination with social factors, can provide information on when and where changing weather patterns could result in increasing numbers of cases of, for example, heat stress or an infectious disease.

Adaptation is needed for our healthcare infrastructure. For example, in coastal regions, many hospitals and clinics are located in areas subject to flooding, as was witnessed in Houston, Miami, and Puerto Rico following hurricanes in 2017[2]. This also is true in many other coastal communities. Mapping which hospitals may be subject to various levels of inundation is an important step; figure 5 shows the locations of hospitals in Charleston County, South Carolina, and Miami-Dade County, Florida, with respect to storm surge inundation for different categories of hurricanes making landfall at high tide[2]. Colors indicate the lowest category hurricane affecting a given location, with darker blue shading indicating areas with the greatest susceptibility to flooding and darker red dots indicating the most vulnerable hospitals. Four of the 38 (11%) hospitals in Miami-Dade County face possible storm surge inundation following a Category 2 hurricane; this could increase to 26 (68%) following a Category 5 hurricane. Charleston hospitals are more exposed to inundation risks. Seven of the 11 (64%) hospitals in Charleston County face possible storm surge inundation following a Category 2; this could increase to 9 (82%) following a Category 4. The impacts of a storm surge will depend on the effectiveness of resilience measures, such as flood walls, deployed by the facilities.

Figure 5: Hospitals at risk from storm surge by hurricanes in Miami-Dade County, Florida and Charleston County, South Carolina



Data from National Hurricane Center 2018 and the Department of Homeland Security 2018

In addition, healthcare facilities may benefit from modifications to prepare for potential future extreme weather and climate events. For example, Nicklaus Children's Hospital, formerly Miami Children's, invested $11.3 million in a range of technology retrofits, including a hurricane-resistant shell, to withstand Category 4 hurricanes for uninterrupted, specialized medical care services[2]. The hospital was able to operate uninterrupted during Hurricane Irma and provided shelter for spouses and families of storm-duty staff and some storm evacuees.

Adaptation efforts outside the health sector can have health benefits when, for example, infrastructure planning is designed to cool ambient temperatures and attenuate storm water runoff and when interagency planning initiatives involve transportation, ecosystem management, urban planning, and water management[2]. Adaptation measures developed and deployed in other sectors can harm population health if they are developed and implemented without taking health into consideration.

Health co-benefits of mitigation policies and technologies

Most policies to reduce emissions have health benefits for the health of Americans in the near and long term. The NCA4 concluded:

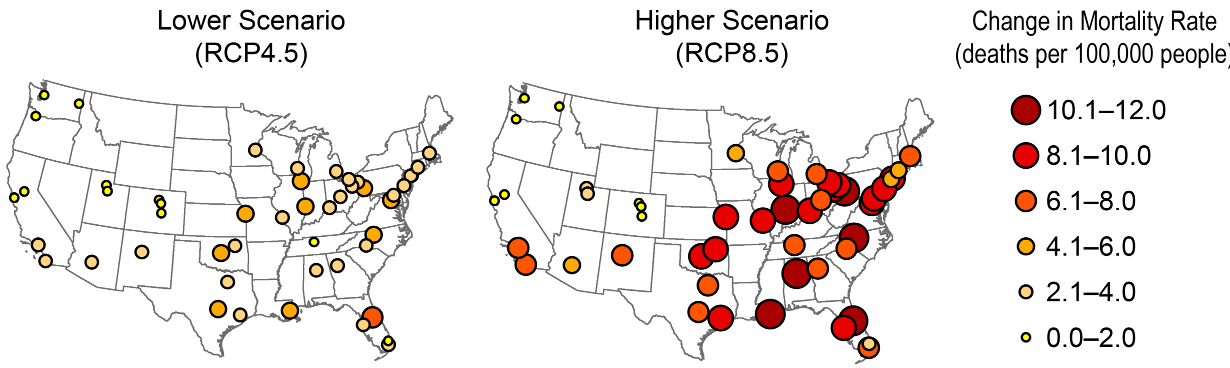
> *Reducing greenhouse gas emissions would benefit the health of Americans in the near and long term. By the end of this century, thousands of American lives could be saved and hundreds of billions of dollars in health-related economic benefits gained each year under a pathway of lower greenhouse gas emissions.*

Policies to reduce greenhouse-gas emissions in the energy sector, housing, and the built environment more generally (ranging from buildings to parks); transportation; and agriculture and food systems can result in near-term benefits to human health[6]. These benefits can arise from reduced exposure to air pollution, particularly fine particulates (particulate matter with a diameter of ≤2.5 µm (PM2.5), including black carbon) and ground-level ozone (levels of which may increase with climate change).

There is a growing literature in which the health benefits of reductions in air pollution as a result of climate-change mitigation strategies are quantified. For example, under a scenario of lower greenhouse gas emissions (RCP4.5), by the end of this century, thousands of lives could be saved and hundreds of billions of dollars of health-related costs could be avoided compared to a scenario of higher emissions (RCP8.5)[2]. Annual health impacts (including from temperature extremes, poor air quality, and vector-borne diseases) and health-related costs are projected to be approximately 50% less under lower greenhouse gas emissions (RCP4.5) than under higher emissions (RCP8.5). The projected lives saved and economic benefits are likely to underestimate the true value because they do not include benefits of impacts that are difficult to quantify, such as mental health or long-term health impacts.

For example, figure 6 shows estimated changes in annual net mortality due to extremely hot and cold days in 49 U.S. cities for 2080–2099 as compared to 1989–2000[2]. Across these cities, the change in mortality is projected to be an additional 9,300 deaths each year under higher greenhouse gas emissions (RCP8.5) and an additional 3,900 deaths each year under lower emissions (RCP4.5). There is an approximate 50% reduction in these estimates under the assumption that the human health response to extreme temperatures in all 49 cities was equal to that of Dallas today (for example, as a result of availability of air conditioning or physiological adaptation). For example, in Atlanta, an additional 349 people are projected to die from extreme temperatures each year by the end of century under RCP8.5. Assuming residents of Atlanta in 2090 have the adaptive capacity of Dallas residents today, this number is reduced to 128 additional deaths per year.

Figure 6: Projected change in annual extreme temperature-related mortality[2]



Cities without circles should not be interpreted as having no extreme temperature impact. Data were not available for the U.S. Caribbean, Alaska, and Hawaii and the U.S.-Affiliated Pacific Islands regions.

Other examples include:[2]

- Under higher emissions (RCP8.5), almost two billion labor hours are projected to be lost annually by 2090 from the impacts of temperature extremes, costing an estimated $160 billion in lost wages (2015 dollars). States within the Southeast and Southern Great Plains regions are projected to experience higher impacts, with labor productivity in jobs with greater exposure to heat projected to decline by 3%. Some counties in Texas and Florida are projected to experience more than 6% losses in annual labor hours by the end of the century.
- Annual national cases of West Nile neuroinvasive disease are projected to more than double by 2050 due to increasing temperatures, among other factors, resulting in approximately $1 billion per year in hospitalization costs and premature deaths under higher emissions (RCP8.5; 2015 dollars). In this same scenario, an additional 3,300 cases and $3.3 billion in costs (2015 dollars) are projected each year by the end of the century. Approximately half of these cases and costs would be avoided under lower emissions (RCP4.5).
- By the end of the century, warming under a higher scenario (RCP8.5) is projected to increase the length of time recreational waters have concentrations of harmful algal blooms (cyanobacteria) above the recommended public health threshold by one month annually; these bacteria can produce a range of toxins that can cause gastrointestinal illness, neurological disorders, and other illnesses. The increase in the number of days where recreational waters pose this health risk is almost halved under lower emissions (RCP4.5).

Although the health benefits of policies to reduce carbon emissions are potentially large, there may be unintended adverse consequences[6]. An example is the introduction of diesel engines that were sometimes promoted to reduce greenhouse-gas emissions but release more fine particulates and nitrogen oxides than gasoline engines. Poorly designed food and agricultural policies to reduce greenhouse-gas emissions could threaten food security by limiting protein sources and increasing food prices for the poor. In addition, increased exposure to household air pollution could result from improving the energy efficiency of households through the use of insulation and draft proofing without improving ventilation. Mitigation policies must consider and minimize these potential harmful effects.

Conclusion

Climate change is affecting the health of Americans, with the magnitude and pattern of future harms dependent on the urgency and level of ambition in designing and implementing adaptation and mitigation measures that will promote and protect our health and our public health and healthcare infrastructure as the climate continues to change.