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ASPR TRACIE

Climate Change Resilience and Healthcare System Considerations



Introduction

Climate change continues to negatively impact national security, environmental stability, and human health conditions. In 2020, over 20 climate-related disasters occurred in the U.S., resulting in over \$1 billion in losses ([Smith, 2021](#)). Climate models predict an increase in adverse health effects over the next century that will intensify existing and emerging health threats ([Crimmins, Balbus, Gamble, et al., 2016](#)). To preserve healthcare delivery capabilities, public and private sector health leaders, and emergency management partners should incorporate climate change impacts into their emergency preparedness and response planning initiatives.

This document provides an overview of climate trends in the U.S., outlining the impacts of climate-related illness and injury on health system¹ operations, care delivery, and patient surge. It touches on the importance of bolstering healthcare infrastructure resilience, facility hardening, and highlights three areas being affected by various elements of climate change.

The intended audience for this document is healthcare executives and emergency planners. It could also benefit representatives from various healthcare, public health, and emergency management organizations, mental health professionals, and school-based health professionals. Key considerations can help planners understand how to better protect their workforce, communities, and at-risk populations known to be disproportionately exposed to climate threats. The document also complements existing climate science and federal initiatives such as the U.S. Department of Health and Human Services (HHS) [2021 Climate Action Plan](#), The White House [Justice 40 Initiative](#), the U.S. Global Change Research Program's [The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment](#), and the Intergovernmental Panel on [Climate Change's Climate Change 2022: Impacts, Adaptation and Vulnerability](#) report. For more information on equity, access the ASPR TRACIE [Disasters and Healthcare Disparity Topic Collection](#) and the [HHS Office of Climate Change and Health Equity \(OCCHE\)](#).

Overview of Climate Change Threats Facing Healthcare in the U.S.

Climate Trends Affecting Natural Disasters in the U.S.

This section discusses overall climate change trends across the U.S. and how they affect the intensity and frequency of natural disasters and extreme weather patterns in differing regions.

As the climate crisis continues to change the natural environment, weather patterns and natural disasters in the U.S. are shifting from short-term acute events to longer-term ongoing chronic events. Several

¹ *The National Academy of Engineering and the Institute of Medicine Committee on Engineering and the Health Care System define the healthcare system as a four-level model: (1) the individual patient; (2) the care team, which includes professional care providers (e.g., clinicians, nurses, pharmacists, and others), the patient, and family members; (3) the organization (e.g., hospital, clinic, nursing home, etc.) that supports the development and work of care teams by providing infrastructure and complementary resources; and (4) the political and economic environment (e.g., regulatory, financial, payment regimes, and markets), the conditions under which organizations, care teams, individual patients, and individual care providers operate.*

The Centers for Disease Control and Prevention's (CDC) [One Health concept](#) is a "collaborative, multisectoral, and transdisciplinary approach" that recognizes the connection between animal, plant, and human health. As climate change continues to disrupt the shared environment, it will also negatively impact health outcomes among these related populations.

geographic locations across the nation are experiencing simultaneous events related to climate change and other hazards, such as public health emergencies, civil unrest, and cyberattacks.

These secondary or dual disasters further stress healthcare systems, threaten the health outcome of at-risk populations, and impact the stability of critical infrastructures. For example, the west coast has experienced a combination of heat waves and wildfires during the COVID-19 pandemic.

According to [The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment](#) and the CDC's [Climate Effects on Health](#) webpage, major climate threats in the U.S. include:

- **Rising Temperatures and Heat Waves.** The Northern and Western regions of the U.S. have been disproportionately impacted by warming temperatures, with the Western region experiencing the highest increase in frequency and intensity to date. Alaska has warmed twice as fast as the global average since the 1950s, and since the 1990s record-high temperatures have occurred three times as often as record lows ([Reidmiller, Jay, Avery, et al., 2018.](#))
- **Wildfires.** Intense wildfires in the Western region of the U.S. have increased in frequency and duration, starting earlier in the spring, and lasting later into fall. They have burned more acreage than previous events with increased intensity causing new and more destructive fire behaviors. The resulting smoke, which contains hazardous substances such as carbon monoxide, ozone, toxic chemicals, and fine and coarse particles, adversely affect populations in close proximity and thousands of miles downwind.
- **Droughts.** While short-term or more seasonal droughts are expected to increase in most areas of the country, a marked increase has already occurred in the West. Similarly, the Southwest has also experienced record persistent droughts that are expected to intensify.
- **Cold Waves and Winter Storms.** Although cold waves have become less frequent or intense across the U.S., winter storms have increased in frequency and severity with their tracks shifting northward.
- **Extreme Precipitation, Floods, and Flash Flooding.** Over the last several decades, heavy downpours have surged across the country. These rainfalls are projected to increase nationally in the winter and spring, with the largest increases projected in the Midwest and Northeast regions. Acidic rain which dissolves limestone, or similar rock, beneath the soil increases the risk of sinkholes, depressions in the ground that do not have natural external surface drainage ([U.S. Geological Survey, n.d.](#)), that further threaten critical infrastructures.
- **Hurricanes.** In the North Atlantic, hurricanes have increased in intensity, frequency, and duration since the early 1980s. Changing tropical storm patterns, such as a poleward shift in the Northwest Pacific basin, and a northward shift in the Atlantic, have increased the frequency of storms in the Northeast Pacific and along highly populated northeastern corridors. Continuous warming has also

Access ASPR TRACIE's [Healthcare System Preparedness for Secondary Disasters during COVID-19](#) report for more information on dual disasters.

Access the [Climate Change Indicators in the United States](#) to review information on indicators for these various climate threats.

intensified hurricane events, raising precipitation levels, increasing sea surface temperatures, and affecting tropical storm wind speeds and coastal storm damage.

- **Rising Sea Levels and Other Negative Effects to Seawater.** Sea levels along the Mid-Atlantic and parts of the Gulf Coast, Caribbean, Puerto Rico, and the U.S. Virgin Islands continue to rise and contribute to increased “nuisance” or coastal flooding. Over the next several decades, this sea level rise and land subsidence (or the gradual settling or sudden sinking of the Earth’s surface) can combine with storm surges and high tides to cause increased coastal flooding. High levels of carbon dioxide (caused by fossil fuels and land use changes) and acidification - primarily caused by the uptake of carbon dioxide - will adversely affect water levels and pH balance in oceanic ecosystems ([National Oceanic and Atmospheric Administration, n.d.](#)).

The Impact of Climate Change on Human Health in the U.S.

This section highlights how the environmental risks previously outlined in this document adversely affect health outcomes in populations experiencing climate-related threats.

According to [Deitchman, et al. \(2021\)](#), climate-related events impact human health in two ways: they directly cause illness, injury, increased mental health trauma, and loss of life (e.g., a tornado, hurricane, or other extreme weather event) or they indirectly affect population health by disrupting living conditions, access to care or public services, damaging critical infrastructure, or impacting economic systems (e.g., secondary results of extreme weather events).

Climate change can also lead to population shifts where an increase in population density, in historically less populated areas, occurs as a result of a significant weather event that causes residents to move. Healthcare and social systems must adjust plans accordingly for these changes in population growth and migration.

According to [Crimmins, et al. \(2016\)](#) and [CDC \(2021\)](#), human health is impacted by climate change in the following ways:

- **Temperature Fluctuations.** Global warming not only results in changes to arctic temperatures, but also affects the jet streams that impact weather patterns. During extreme temperature events, the body’s ability to regulate its internal temperature is affected.
 - » **Extreme heat** can result in dehydration, heat exhaustion, edema, syncope, heatstroke, hyperthermia, and acute cerebrovascular accidents (contributing to thrombogenesis). While few deaths are directly attributed to heat, most illness related to heat waves are caused by the exacerbation of existing medical conditions (e.g.,

Natural disasters can be powerful mechanisms of direct and indirect hazardous materials releases. These natural hazards can trigger technological malfunctions (na-tech events), that pose unique environmental and human hazard ([Young, Balluz, and Malilay, 2004](#)).

According to the U.S. [Environmental Protection Agency \(2021\)](#), urban areas, where structures such as buildings, roads, and other infrastructure are highly concentrated and greenery is limited, can become “islands” of higher temperatures relative to outlying areas. This is known as the “heat island effect.”

chronic pulmonary disease, cardiac conditions, kidney disorders, and psychiatric illness). Higher temperatures can increase the risk of mental health conditions, such as suicide ([Thompson, Hornigold, and Page, 2018](#)), and certain medications increase health risks by altering thermoregulation, cognitive alertness, blood pressure, cardiac output, sweat mechanisms, and electrolyte balance ([The Lancet, 2015](#)). People with a limited ability to regulate body temperature, and individuals experiencing homelessness who are at an increased risk of exposure, may be particularly susceptible to extreme heat conditions. Extreme heat in urban settings is a large focal area.

- » **Extreme cold** can lead to frostbite and hypothermia worsening existing conditions such as cardiovascular, respiratory, cerebrovascular, and diabetic diseases. Indirect injuries and deaths linked to extreme cold include exhaustion from shoveling snow, medical emergencies related to traffic incidents, transportation barriers that limit access to care (e.g., blocked, or icy roads), and fires or carbon monoxide poisoning caused by inappropriate heat sources. As with extreme heat, people with limited ability to regulate body temperatures and individuals experiencing homelessness may be particularly susceptible to extreme cold conditions.
- **Natural Disasters.** The World Meteorological Organization [reports](#) that weather-related disasters have increased five-fold over the past 50 years. Each event has its own impact on health and the healthcare system; this is not an exhaustive list. For additional information on plans and lessons learned, visit the ASPR TRACIE [Natural Disasters Topic Collection](#).
 - » **Flooding/flash flooding** related to extreme precipitation, hurricanes, coastal storms, and tsunamis can cause traumatic injury and death from drowning. It is associated with preterm births, low birth weight, and carbon monoxide poisoning related to power outages and inappropriate use of generators. Healthcare facilities may be impacted by infrastructure damage or disruptions, and experience patient surge due to the spread of infectious diseases post-disaster. As previously addressed, acid rain increases the risk of sinkholes, which in addition to causing severe structural damage, can contribute to physical injury and death.
 - » **Droughts** contribute to reduced water quality, quantity, and access; respiratory impacts due to reduced air quality; decreased sanitation and hygiene; increased incidence of disease; and increased mental health distress.
 - » **Wildfires** cause smoke inhalation, severe coughing, and wheezing; flames can cause severe burns and other traumatic injuries that increase heart rate, chest pain, headaches, irritated sinuses, and sore throat. For certain individuals, wildfires and smoke can exacerbate asthma, chronic obstructive pulmonary disease, and other respiratory illnesses. Impacts from wildfires can lead to mental health distress and illness related to hazardous material exposure from damaged infrastructures (e.g., contamination of water systems).
 - » **Winter storms** can lead to traumatic injury and death, carbon monoxide poisoning related to power outages, and hypothermia or frostbite. For additional information, review the extreme cold information previously covered in this section.

- » **Severe thunderstorms, tornados, derechos (windstorms), and other [types of damaging winds](#)** can lead to traumatic injury and death (e.g., cranial, chest, spinal, and peripheral nerve injuries). Post-injury concerns include fungal or necrotizing soft-tissue infection, respiratory infections- particularly those caused by uncommon microbes as seen in individuals who live or work in a tornado zone, and carbon monoxide poisoning caused by inappropriate use of generators (to manage power outages).
- **Air Quality Impacts (e.g., air pollution and pollen concentration).** Increased air and ground-level ozone levels are associated with premature deaths and can exacerbate asthma-related conditions, chronic obstructive pulmonary disease, emphysema, and other breathing difficulties. As extreme temperature fluctuations interact with air pollution, they further affect the human physiological response to contaminated air.
- **Vector-borne Diseases.** In the U.S., the emergence or re-emergence of disease-carrying vectors (from ticks, mosquitoes, and fleas) and expansion of zoonotic disease risk is expected to increase due to climate change. Examples include lyme disease, West Nile virus, locally acquired dengue (as have been observed in Florida and southern Texas), and chikungunya (recently found in southern Florida).
- **Water-related Illness.** Water-related illnesses caused by pathogens such as bacteria, viruses, protozoa, and toxins—produced by algae and cyanobacteria (i.e., blue-green algae) and chemicals introduced into the environment—have increased as a result of changing weather patterns. Exposure can adversely affect human health through ingestion, inhalation, or direct contact with contaminated drinking or recreational water and through consumption of infected fish and shellfish. Health symptoms from water-related illnesses may include but are not limited to gastrointestinal illness (e.g., gastroenteritis, diarrhea, and vomiting), neurological disorders, respiratory distress (e.g., mild to severe influenza-like illness), meningitis, organ failure, and dermal infections.
- **Food Safety.** The systems and processes related to food safety, nutrition, and production are interrelated with their physical and biological environment. Increases in foodborne illness are expected to rise as climate change impacts environmental variables (particularly flooding, drought, and temperature fluctuations). These environmental factors can shift the seasonal and geographic occurrence of bacteria, viruses, pests, parasites, fungi, and other chemical contaminants, which can lead to foodborne hazards. Gastrointestinal infections may range in severity from nuisance symptoms to life-threatening. In serious cases, certain foodborne infections can lead to miscarriages, stillbirths, premature delivery, or life-threatening infections such as meningitis, or inflammation of other organs. The climate crisis also impacts food security. As weather patterns change, natural disasters increase, and fragile ecosystems are altered, food supplies are adversely affected, impacting nutritional resilience.
- **Mental Health.** According to CDC's [Climate Effects on Health](#) webpage, people may experience negative mental health effects related to climate change, regardless of their health histories. Long- and short-term impacts can include minimal stress and symptoms of distress to more severe clinical disorders including anxiety, depression, and post-traumatic stress. Natural disasters trigger predictable stress reactions and can negatively affect people with existing mental health conditions. Cumulative heat and cold stressors related to employment (e.g., farmers worried about crop

growth during droughts) can have significant mental health impacts. Symptoms may be short-lived or chronic. Some patients with severe mental illness (e.g., schizophrenia or dementia) may be at higher risk for hospitalization and death during heat waves because their medications may interfere with temperature regulation or may contribute to hyperthermia. One research study found a direct relationship between temperature and incidence of suicide in the U.S. ([Mullins, and White, 2019](#)). [Crimmins, et al.](#) wrote “The frequency of interpersonal violence and intergroup conflict may increase with more extreme precipitation and hotter temperatures. These impacts can include heightened aggression, which may result in increased interpersonal violence and violent crime, negatively impacting individual and societal mental health and well-being.” Cumulative stressors can also lead to a higher incidence of child abuse.

Healthcare Infrastructure Resiliency/Hardening

To combat the ongoing negative effects of climate change on human health and mental wellness, governmental agencies, healthcare systems, community organizations, and health experts are developing solutions aimed at decelerating global warming, mitigating impacts, increasing health system resilience, and expanding climate crisis research. HHS found that “Increasing incidents of extreme weather represent complex hazards that challenge accepted baseline assumptions for infrastructure capabilities, redundancies, and disaster preparedness and response. Climate change is introducing new threats and new building design threshold conditions” ([Guenther, and Balbus, 2014](#)). At the regional, state, and local levels, sustainable and resilient development practices and preparedness levels vary. The same resource states, “there is no acknowledged universal ‘baseline’ with regard to the ability of health care infrastructure to withstand impacts of extreme weather events.” This statement holds true years after publication.

Healthcare executives and emergency planners have a responsibility to ensure their facilities are safe for staff, patients, and visitors. This includes ensuring the healthcare infrastructure (the physical buildings) is resilient to extreme weather events; planning for impacts to major utilities (e.g., electricity, water, wastewater, Internet), personnel (both medical and supportive staff), and the supply chain; and investing in backup capabilities, all of which are essential to the delivery of medical care.

Under the Services Sustainable and Climate Resilient Health Care Facilities Initiative (SCRHCFI), HHS developed the [Climate Resilient Health Care Facilities Toolkit](#), which can help healthcare executives and emergency planners learn more about implementing best practices in climate resilience. It is based on a framework

Related Resources:

ASPR TRACIE. (2022). [Climate Change and Healthcare Systems Topic Collection](#).

American Meteorological Society. (2014). [A Prescription for the 21st Century: Improving Resilience to High-Impact Weather for Healthcare Facilities and Services](#).

Guenther, R., and Balbus, J. (2014). [Primary Protection: Enhancing Health Care Resilience for a Changing Climate](#). U.S. Department of Health and Human Services.

U.S. Department of Health and Human Services Sustainable and Climate Resilient Health Care Facilities Initiative (SCRHCFI). (2016). [Climate Resilient Health Care Facilities Toolkit](#).

composed of the following five elements: Climate Risks and Community Vulnerability Assessment; Land Use, Building Design, and Regulatory Context; Infrastructure Protection and Resilience Planning; Essential Clinical Care Service Delivery Planning; and Environmental Protection and Ecosystem Adaptations.

Considerations for Healthcare Executives and Emergency Planners

The following lists of general considerations (regardless of a specific weather event unless noted otherwise) can be used by healthcare executives and emergency planners when planning for preparedness, response, and recovery efforts as they pertain to the health impacts caused by climate change.

“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” (Crimmins, et al., 2016).

General Considerations for Healthcare Executives and Emergency Planners

Immediate Action Steps

Identify priority climate change impacts specific to [your geographic region](#). Understand how these disaster risks will impact healthcare operations. Plan for the release of hazardous materials as a result of a technologic malfunction precipitated by a natural event.

Use the [Climate Resilient Health Care Facilities Toolkit](#) to help learn more about implementing best practices in climate resilience.

Conduct/update your healthcare system/facility-level [hazard vulnerability assessment \(HVA\)](#). Ensure climate change factors are identified, prioritized, and addressed appropriately. Factor in weather events that are more severe or protracted than previous ones and include events not historically experienced in your region (e.g., the 2021 ice storms in Houston, TX).

Update your healthcare system/facility-level surge plans to ensure the maximum level of preparedness for sudden increases in patient load. Establish planning triggers for when to activate the surge plans.

Develop and maintain healthcare system/facility-level utility outage plans. Work closely with your emergency operations center staff and representatives from your power providers to ensure utilities are not interrupted and healthcare facilities are prioritized for restoration. Ensure adequate back-up power is in place. Include alternate forms of power generation and storage (e.g., solar, wind). Incorporate planned temporary power outages intended to prevent wildfires or overloading the power grid during extreme incidents, which may last a few hours or extend for many days, into plans.

Explore alternative utility sources (e.g., microgrids, drilling a well, establishing solar or wind power). Consider feasibility, costs versus benefits, and resource needs (human and technological).

Prepare for secondary impacts that will accompany climate impacts (e.g., utility outages, water shortages, supply chain issues, and impacts to temperature-sensitive medical equipment).

Ensure sufficient levels of supplies available to sustain operations. Work with vendors and community response partners to ensure supplies will be delivered in a timely manner. 96-hour sustainability was the previous benchmark, but the COVID-19 pandemic and increases in severe weather events have shown healthcare planners this may not be sufficient. Determine what level of preparedness is appropriate for your organization.

Establish/bolster collaborative relationships and mutual aid strategies with traditional and non-traditional partners, such as emergency medical services (EMS), public health agencies, private physician offices, healthcare coalitions (HCCs), dialysis providers, schools or school-based wellness centers, public transportation, and school transportation services (which may be mobilized and used for immediate evacuation). Include other provider contract groups. Ensure rural areas address challenges finding available services and facilities given their expansive geographical areas ([Rogan, and Lewis, 2020](#)).

Activate the Hospital Incident Command System to respond to a climate-related disaster or natural-technological event. This will ensure common structures, terminology, communications, objectives, and management of information and resources within the healthcare system and externally with partners. NOTE: As previously addressed in this document, natural-technologic events pose unique environmental and human hazards. These types of events are caused by natural events that trigger technologic malfunction and consequently release hazardous materials ([Young, Balluz, and Malilay, 2004](#)).

Determine core healthcare services that will be provided during different adverse events and those which will be suspended.

Ensure language access and effective communication are available during response and recovery ([HHS, n.d.](#)).

Provide clear, concise messaging to staff, volunteers, patients and their caregivers, and the community during and after a natural disaster. Ensure internal agency and external community alert systems are operational and tested frequently, and that public messaging plans are maintained.

Short-term Action Steps

Consider secondary/dual disasters, such as the ones that struck during the COVID-19 pandemic (e.g., natural disasters, cyberattacks, large-scale transportation accidents, mass casualty incidents) which will further stress the health system and threaten at-risk populations and infrastructure.

- » Climate change has drastically increased the need for general population shelters for people displaced by wildfires, floods, landslides, and other disasters. Implementing infection control and other safety measures within shelters is critical. Plan for shelters that will be open for months or longer; apply these considerations to similar public spaces needed as a result of climate change (e.g., cooling/warming centers). Regular communication with local organizations will ensure patients and community members are aware of such resources.
- » Shelter operations must accommodate people with disabilities. Support references include: the U.S. Department of Justice's Americans with Disabilities Act Checklist for Emergency Shelters, and the U.S. Federal Emergency Management Agency's (FEMA) Guidance on Planning for Integration of Functional Needs Support Services in General Population Shelters.

Assess your Community Resilience Estimates and Area Deprivation Index (ADI) and Social Vulnerability Index (SVI) to determine mitigation strategies for communities vulnerable to climate change impacts (e.g., protection from flooding by raising dikes). Identify methods to improve pre-event planning (e.g., establishing cooling centers for heat emergencies). Coordinate with response partners to identify at-risk communities and critical infrastructure facilities.

Evaluate or reassess how people who live/work in settings that put them at increased/higher risk of becoming infected or exposed to hazards are served by your health system.

Understand how they may experience disproportionate, multiple, or complex risks to their health in response to climate change. Populations of concern may include communities of color, lower income communities, immigrant groups, the elderly, children, individuals with disabilities, and people with limited English proficiency.

- » Use the following tools to ensure social determinants of health are addressed: HHS' Healthy People 2030: Social Determinants of Health, and the U.S. Census Bureau's Census Community Resilience Estimates (CRE) program (which includes maps and tables of the most up-to-date demographic characteristics and the Census Tract).

Plan for a patient surge from evacuated communities.

Conduct Targeted Outreach. Partner with local law enforcement, public health, environmental health, social services, HCCs, and other community-based partners to engage individuals via phone calls and in-person health and wellness visits. Consider how to engage individuals without phones and/or internet services) ([HHS emPOWER Program](#) and [Map](#)).

- » Ensure staff conducting community outreach are experienced and knowledgeable in identifying signs/symptoms of illness (e.g., hypothermia, frostbite).
- » Consider that law enforcement may not always have the capacity to aid healthcare workers.

Identify how people with chronic health conditions can continue to access care. Work with HCC stakeholders and healthcare professionals to ensure proper measures are available during a severe weather impacting transportation.

- » Ensure dialysis patients have treatment prescriptions/ transportation plans at alternative care sites in the event their usual dialysis center is closed.
- » Ensure community organizations and partners have shelters available for electric-dependent at-risk groups during an evacuation or power outage.

Maintain sustained healthcare services in your community during a prolonged extreme weather event/ natural disaster. Collaborate with response partners via your HCC to ensure continuity of services. For more information on HCC across the country, review the [HHS ASPR Health Care Readiness Programs Portfolio webpage](#). Identify resources to support mitigation efforts of long-term care facilities, private medical practices, pharmacies, and similar outpatient healthcare providers. Determine how your health system will manage patient surge if other healthcare providers are unable to continue providing services. NOTE: Determine which long-term care facilities have generator back-up that powers their heating, ventilation, and air conditioning (HVAC) systems.

Prepare to expand telehealth capabilities and temporary phone system alternatives.

Communicate risks posed by extreme weather events to susceptible patients. Collaborate with response partners, organization stakeholders, healthcare professionals to ensure people who live/work in settings that put them at increased/higher risk of becoming infected or exposed to hazards stay informed. Use various communication methods, and ensure you provide clear guidance regarding mitigation strategies and adaptation practices.

Work closely with the closest National Weather Service forecast office to access more granular information than general weather reports to understand potential direct impacts to your healthcare facility.

Cancel elective surgeries and non-emergency appointments and encourage patients to refill prescriptions in advance of an expected disaster.

Educate patients and physicians on medications that can increase the risk of side effects during extreme weather events. Work with pharmacy staff and primary care clinics to identify at-risk populations, heat-susceptible individuals, and those prone to illness during extreme weather events.

Ensure patients are educated on proper storage of medications during high heat conditions. Work with pharmacy staff to ensure information is accurate. Numerous drugs (e.g., antibiotics, epinephrine, analgesics, insulins, and sedatives) are licensed for storage within specific temperature ranges.

Determine how many staff are based locally and could be affected by a disaster. Staff members may have difficulty traveling to work. Develop a strategy with neighboring providers to address how impacted staff could work in alternate provider locations.

Ensure staff are able to receive necessary medical care for injuries incurred at the facility due to the climate-related incident. Understand the regulations, laws, and agreements that are in place from a legal perspective.

Ensure flexible staff scheduling immediately after a disaster.

Consider cross-training staff in preparation for possible shortages and to ensure backup in specific areas of expertise, if needed.

Support employees with financial, or other short-term, needs (as appropriate) following a disaster (e.g., clothes and access to laundry services, daycare/ adult care services, pet care, and home improvement help and materials).

Maintain morale by paying staff as soon as possible, encouraging colleagues to donate vacation time, network with non-affected healthcare facilities to borrow staff with a “no-hire pledge” in place or a pre-defined Memorandum of Understanding.

Future or Long-term Action Steps

Assess and plan for the need to support a changing patient demographic. For example, the western part of the U.S. may expect to see more patients with asthma and other respiratory illnesses due to the increasing frequency of wildfires. Plan accordingly within your healthcare organization.

Plan for a long-term patient surges, in which staff and healthcare facilities may require sustained levels of resources.

Be proactive in hardening your healthcare facility’s capabilities. Plan ahead to mitigate risk from adverse weather events. Consider alternative power generation and storage capabilities.

Be aware of the likelihood of adverse events that may not directly threaten your facility but may have profound effects on your patients and their ability to access care (e.g., road hazards/closures that delay or prevent EMS from reaching 911 callers).

Provide education and training opportunities for clinicians and staff to understand the health impacts of climate change, particularly regionally specific impacts facing their most vulnerable patients. Specific emphasis should be on clinicians working with older, asthmatic, and obstetric patients, given the vulnerability of these groups to heat stress.

Consider what healthcare policies, preparedness frameworks can be developed, changed, or updated to ensure resilience and proper planning for future environmental hazards and climate-related dangers.

Ensure hospital leadership and staff understand protocols for seeking assistance during a disaster, including:

- » Engaging with local public health and emergency management agencies.
 - » Knowing the various federal legal authorities in an emergency declaration or public health emergency.
 - » Understanding Medicare waiver authorities and FEMA reimbursement policies for federally declared disasters.
 - » Tracking data for health outcomes related to climate change events and conducting appropriate recordkeeping (e.g., staff overtime, special expense spending on supplies).
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The [HHS emPOWER Emergency Preparedness Dataset](#), along with local electric cooperative and company information, can help identify at-risk individuals in areas impacted by prolonged power outages that use electrically powered medical equipment such as oxygen concentrators and home ventilators.

Healthcare Financial/Economic Considerations

The following considerations specifically address financial and economic aspects of healthcare systems.

Immediate Action Steps

Examine the cost and feasibility of increasing nursing and other staffing levels via traditional and non-traditional means such as use of overtime hours to bridge the gap until new staff can be recruited.

- » If staffing levels need to be increased for an extended period of time, consider the time and resources needed to recruit new staff within your health system's labor market. Determine if the period that the health system can increase staffing through overtime use is sufficient until new staff can be recruited; understand how these changes will impact financial margins.

Consider implementing the [Nurse Licensure Compact \(NLC\)](#) to increase access to nurses while maintaining public protection at the state level. Under this compact, nurses can practice in other NLC states and are not required to obtain additional licenses. This type of staffing strategy is relied upon heavily by some healthcare organizations such as dialysis centers.

Short-term Action Steps

Determine if any climate-related threats require specific mitigation efforts or could adversely affect the hospital bond rating. Work with insurers and financial officers to address specific issues.

Identify strategies for rapidly augmenting staff and resources at facilities impacted by severe weather and/or natural disaster events.

Model how a 1 percentage, or more, point change in payer mix toward Medicaid patients and away from commercial patients would impact the financial health of your health system. Understand if a substantial loss of employment would increase Medicaid enrollment in your area.

Determine how care will be delivered in rural areas in the event of a severe weather event. Determine the viability of current care models in relation to a potential decrease in overall patient volumes (e.g., decreased inpatient, emergency department [ED], outpatient, laboratory, and imaging numbers).

- » Model the degree to which a 1-3 percentage-point change over a specific period of time would be financially detrimental.
- » Consider how FEMA, the Centers for Medicare & Medicaid Services, or other federal programs can assist in lessening the financial burden of lost patient volumes.

Future or Longer-term Action Steps

Evaluate and plan for possible long-term financial impacts that your healthcare system may face due to adverse climate-related events.

- » This includes infrastructure protection and mitigation costs such as increasing backup generator capacity or establishing floodwalls; potential staffing impacts and resource shortages such as a breakdown in the supply chain; changes in operating costs (e.g., utility, equipment, supplies, and food); and an increase or decrease in regular patient admissions.

Attempt to determine the variability in case volumes by type based on potential climate events that are most probable for your hospital or health system. Note that some health systems may not have the predictive modeling capability necessary.

- » Evaluate if the gross margins would be negative for cases that are expected to increase, and conversely, if the gross margins would be positive for cases that are expected to decrease.
- » Accordingly, assess how small shifts in the expected mix of cases due to the probable climate event would impact the financial health of your health system.
- » Determine if your health system expects the average length of stay to increase due to complications associated with the climate event. If so, will this have financial implications given the diagnosis-related group reimbursement (DRG) payment system; would this change if the average DRG-severity adjustment per admission is also increased.

Evaluate your healthcare system's ability to access emergency financing (e.g., emergency funds, grants, any other relevant sources of income). Ensure the necessary leadership and staff are familiar with these types of application procedures for state and federal assistance.

REGIONAL INSIGHTS

Two reports – [Climate Change & Health: Assessing State Preparedness](#) (Johns Hopkins Bloomberg School of Public Health, and Trust for America’s Health, 2020) and [The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment](#) (Crimmins, Balbus, Gamble, et al., 2016) – provide data on state preparedness levels for the health effects of climate change. To date, the data indicate a great deal of variation among state readiness plans. While the examples in this section illustrate some key issues for general healthcare systems, *it is critical that each health system recognize the specific indicators of negative climate change effects in their area and incorporate them into their business and facility plans.*

The ASPR TRACIE Team selected the following three geographic areas for regional insight based on the authors’ rankings of locations that were categorized as *least/moderately prepared and most vulnerable*, as well as specific instances that directly impacted these areas and their healthcare systems:

- San Francisco Bay Area
- Southeast Texas
- Central Tennessee

These regional insights provide an overview of the region’s vulnerabilities to climate change, and the climate-related impacts that can adversely affect human health and healthcare systems. *Healthcare executives and emergency planners should consider their region’s climate and equity-specific vulnerabilities when developing or updating their plans.* Potential considerations/action steps for this target audience were previously identified in this document and are not readdressed in this section.



REGIONAL INSIGHT # 1: SAN FRANCISCO BAY AREA, CA

Overview of San Francisco Bay Area Vulnerabilities to Climate Change

Previous California (CA) wildfires mostly occurred from June through November. However, over the past several years, that trend has changed with wildfires starting earlier and ending later ([California Department of Forestry and Fire Protection \[CAL FIRE\], 2021](#)). As increased drought conditions and warmer temperatures continue across the state, researchers conclude that more wildfires are now occurring October through April.

In Northern California this change is caused by the Diablo winds. In Southern California it is caused by the Santa Ana winds that carry dry air from the Great Basin ([Pierre-Louis and Schwartz, 2021](#)). These fires burn faster and cause increased destruction as embers are carried by the wind. According to [Cal Fire](#), the top eight largest wildfires in CA occurred within the last five years.

The combination of more fires, and warmer drier conditions, may expand CA deserts (Sonoran, Mojave, and Great Basin) and ultimately change parts of the state's landscape. Higher temperatures and drought are likely to increase the severity, frequency, and extent of wildfires, affecting human health, property, and overall livelihood.

As part of the [California's Fourth Climate Change Assessment](#), several regional reports were developed, including the [San Francisco Bay Area Summary Report](#) (2021) that covered nine counties, 100 cities and towns, and a population of more than seven million people across the bay area.

[The report](#) identified the following impacts of climate change on the region:

- The maximum temperature has increased by an average of 1.7 degrees Fahrenheit (0.95 degrees Celsius) from 1950-2005.
- Coastal fog – which acts like a “natural air conditioner” and is a critical part of the Bay Area microclimate – is becoming less frequent in the region.
- Sea levels have risen over 8 inches (20 centimeters) in the last 100 years.

“On average, 4 percent of the land in California has burned per decade since 1984.” ([U.S. Environmental Protection Agency, 2016](#))

Related ASPR TRACIE Resources:

[Applying Lessons Learned to Hospital Evacuation](#)

[Challenges and Considerations for Healthcare Facilities and Residents Affected by Planned Power Outages](#)

[Evacuating and Receiving Patients in the Midst of a Wildfire](#)

[Compounding Disaster: Pediatric Triage to Care](#)

[Hospital Evacuation during a Wildfire and Pandemic: Avista Adventist Shares their Experience](#)

[Issue 10: Preparing for and Responding to Wildfires and Planned Outages](#)

[Shelter from the \(Fire\) Storm: Sonoma County's Experience](#)

[The Last Stand: Evacuating a Hospital in the Middle of a Wildfire](#)

[Wildfires and Public Safety: Planned Shutoffs: Napa County's Experience](#)

- From 2015-2016, El Nino effects resulted in a winter wave energy that was over 50% larger than typical winters in the region, causing unprecedented outer coast beach erosion.
- From 2012-2016, CA drought led to the most severe moisture deficits seen in over 1,200 years and a 1-in-500-year low in Sierra Nevada snowpack.

Over the next several decades, these climate changes are projected to increase significantly. Precipitation will continue to exhibit high variability year to year, with very wet and dry years. The average Sierra Nevada snowpack is projected to decline approximately 20% in the next two to three decades as increases in temperature cause longer droughts and pose significant challenges for water supplies, natural ecosystems, and agriculture. Projection models indicate at least two meters of sea level rise over the next several centuries, affecting the Bay Area’s transportation system, wastewater treatment plants, and other critical infrastructure.

Recent Events

On October 8, 2017, an unprecedented wind event led to one of the worst wildfires in Sonoma County history and almost three weeks of fires burning in the area. “In total, the Nuns, Tubbs, and Pocket Fires (together comprising the Sonoma Complex Fire) burned over 110,700 acres in Sonoma and Napa counties. Twenty-four lives were lost as a result of the fires. 6,997 structures were destroyed, resulting in direct losses exceeding \$7.8 billion” ([Sonoma County Ag + Open Space, and The Sonoma County Watershed Collaborative, 2019](#)).

This same year, the Bay Area also experienced an extraordinary heat wave over the 2017 Labor Day weekend. Downtown San Francisco peaked at 106 degrees Fahrenheit that Friday, which was recorded as the hottest temperature in 143 years. This event resulted in three fatalities and 50 hospitalizations for heat-related illness in the city. “The number of 911 calls overwhelmed ambulances and forced San Francisco to request mutual aid from neighboring counties. There were 1,342 emergency calls on Friday, San Francisco Department of Public Health Director of Communications Rachael Kagan said, more than double the number compared to the previous Friday” ([Simons, 2017](#)).

San Francisco Bay Area Climate Change Impacts on Human Health and Healthcare Systems

Climate change in the Bay Area will continue to have negative effects on human health and healthcare systems as trees, shrubs, plants, and other natural material in the environment release toxins when they burn ([Balmes, 2018](#)). Intense smoke from the wildfires reduce air quality and increase medical visits for chest pains, respiratory issues, and heart problems ([U.S. Environmental Protection Agency, 2016](#)). Additional health effects related to wildfire smoke and extreme heat events, include smoke inhalation; burns and other traumatic injury; severe coughing or wheezing; rapid heartbeat; headache; irritated sinuses; runny nose; sore throat; and exacerbated asthma, chronic obstructive pulmonary disease, and other respiratory illnesses. Symptoms from wildfire smoke inhalation also complicate diagnoses of other respiratory diseases

“By 2100, if greenhouse gas emissions continue to rise, one study found that the frequency of extreme wildfires would increase, and the average area burned statewide would increase by 77 percent.” ([State of California Government, 2021](#))

(e.g., healthcare providers faced challenges in assessing levels of COVID-19 and flu infection during the 2020 pandemic when smoke inhalation patients overwhelmed hospitals).

Particulate matter (PM), typically the greatest health concern from wildfire smoke, is comprised of tiny ultrafine particles (at a diameter of 2.5 micrometers [μm] and smaller) that can be inhaled deep into the lungs. This size of particulate matter, often referred to as $\text{PM}_{2.5}$, can then pass directly into the bloodstream, affecting heart and other organ function. “During the 2018 Camp Fire, maximum $\text{PM}_{2.5}$ levels from November 8 through November 22 were more than three times the average levels seen during the same time period from 2010 to 2017” ([California Air Resource Board, 2021](#)).

Healthcare providers should be prepared to assess smoke plume data and anticipate additional respiratory hospitalizations in those areas. During the 2007 San Diego wildfires, visits to the ED increased by 34 percent for respiratory conditions and by 112 percent specifically for asthma. In 2003, during heavy wildfire smoke conditions in Southern California, there was a 34 percent increase in asthma hospital admissions ([California Air Resource Board, 2021](#)).

In addition to the recent human health impacts of wildfires and rising temperatures that the region continues to experience, these conditions are especially dangerous for children, communities of color, low-income households, immigrant populations, older adults, and persons with limited English proficiency. Extreme heat can lead to strokes, dehydration, and affect individual cardiovascular, respiratory, and nervous system function.

The increased frequency and intensity of wildfires, such as those occurring in Sonoma and Napa Counties, along with growing vulnerabilities to extreme heat conditions, contribute to the negative health impacts being experienced by the Bay Areas’ healthcare systems. Hospitals may be the only medical facilities operating during such disasters as primary care services are disrupted ([Rosenthal, Stoker, and Haar, 2021](#)). These hospitals and EDs quickly become overwhelmed by the surge of patients requiring medical care due to smoke and extreme heat exposure that exacerbate chronic medical conditions and negatively impact at-risk citizens seeking assistance. Public transportation may be disrupted, further impacting vulnerable groups seeking healthcare and other services during an emergency event. In addition, cell phone and Wi-Fi services may be disrupted, presenting challenges for healthcare systems, providers, and the community.

In addition, fewer healthcare workers may be available to respond to work, as they are personally impacted by the wildfires. The authors of [one study wrote](#), “a physician noted that over 210 physicians and health workers in his county of more than 180,000 residents lost their homes and were understandably unable to work.” Such large staffing shortages at local hospitals has the potential to largely affect health outcomes within the impacted area.

Wildfires may also require hospitals and healthcare facilities to evacuate some or all patients or shut down completely. Multiple hospitals in a region may have to evacuate simultaneously, creating surges

“Higher temperatures are amplified in urban settings where paved and other surfaces tend to store heat. Warming can also increase the formation of ground-level ozone, a component of smog that can contribute to respiratory problems.” ([U.S. Environmental Protection Agency, 2016](#))

and significant patient tracking challenges. “California hospitals and their surrounding communities are coping with a new reality of intermittent power outages and evacuations amid more frequent and intense wildfires, among other natural and man-made disasters. This has required a more robust, permanent approach to how to pack up and leave quickly and safely, making sure the right supplies and data follow them” (Kacik, 2019). Note that emergency planners should ensure facilities have back-up generators to power HVAC systems in the event evacuation is not plausible, and they should recognize the negative implications that surrounding areas will experience as a result of dispersed smoke from wildfires spreading to other communities.



REGIONAL INSIGHT # 2: SOUTHEAST TEXAS

Overview of Southeast Texas Vulnerabilities to Climate Change

Texas climates, typically characterized by hot summers and cool mild winters, are changing as most of the state has warmed between 0.5 to 1 degree Fahrenheit in the past century. Rainstorms are more intense, floods are more severe, and in the eastern two-thirds of TX, the soil is becoming drier despite the increase in average annual rainfall. Along the coast, the sea is rising nearly two inches per decade, and in the coming decades, storms are projected to become more severe and summers are likely to become increasingly hot and dry.

According to the [National Aeronautics and Space Administration](#), “Texas is ranked first in the U.S. in the variety and frequency of natural disasters. Flooding, wildfires, tornados, hurricanes, hailstorms, sinkholes, erosion, and drought all occur in the state. Sometimes, even utilization of the state’s natural reserves of oil, gas, and water can lead to subsidence and earthquakes.” Land subsidence (the gradual settling or sudden sinking of the Earth’s surface) has caused extensive damage to buildings and infrastructure in Harris County (e.g., the loss of groundwater storage, reactivated faults, generated fissures, and increased seawater intrusion and a loss of wetland habitats).

“Seventy years from now, Texas is likely to have three or four times as many days per year above 100°F as it has today ([U.S. Environmental Protection Agency, 2016](#)).”

In October 2021, the City of Houston released [Houston Climate Impact Assessment 2.0: Understanding Houston’s Past and Future Climate and What it Means for You](#) to identify how future temperature and precipitation will change the greater Houston area through 2100. Specific indicators were used to assess impacts, including the estimated likelihood and frequency of high intensity events (e.g., droughts, heavy rainfall, and heat waves), and increase in chronic stressors (e.g., annual average temperature, number of hot days above 100 degrees Fahrenheit).

In that report, the authors wrote, “Houston has a history of being impacted by many climate and weather extremes. The most recent severe drought in Houston lasted from 2010 to 2015. The drought’s worst impacts were felt in 2011, when the drought combined with one of the worst heat waves on record. From 2015-2019, Houston experienced six large-scale rain events that resulted in significant flooding across much of the city.”

Recent Events

In February 2021, TX was severely impacted by an unprecedented winter storm (Uri). Hospitals and communities endured extended losses of power and water due to overloaded and frozen power grids and frozen/ burst pipes that affected 4.3 million residents, in sub-zero temperatures. The harsh winter storm was particularly unexpected as the Southeast TX region is not accustomed to prolonged periods of freezing weather. In ASPR TRACIE’s [Managing the Storm After the Storm: Healthcare in TX Recovers from Severe Winter Weather \(2021\)](#), three subject matter experts from healthcare systems across the state share their experiences, challenges, and lessons learned during the storm.

Southeast Texas Climate Change Impacts on Human Health and Healthcare Systems

In TX, hotter temperatures will continue to negatively affect human health and healthcare systems. People will become more vulnerable to dehydration, heat exhaustion, edema, syncope, heatstroke, hyperthermia, and acute cerebrovascular accidents (contributing to thrombogenesis). Most illnesses related to heat waves will be linked to the exacerbation of existing medical conditions, such as chronic pulmonary diseases, cardiac conditions, kidney disorders, and psychiatric illness. Heat waves pose risks to certain populations including children, communities of color, low-income households, immigrant populations, the elderly, and people with limited English proficiency.

Warmer air will increase the formation of ground-level ozone, a key element of smog. These increased ozone levels will aggravate lung disease (e.g., asthma) and increase the risk of premature death from heart or lung disease.

Increased flooding, and increased frequency and intensity of hurricanes are also major concerns for this area. Flooding can cause traumatic injury and death from drowning and has been associated with preterm birth and low birth weight. Carbon monoxide poisoning related to power outages and inappropriate use of generators, mold and other environmental issues, loss of housing, poor living conditions, and mental health impacts will all contribute to increased acute and chronic health issues. Due to the increases in water and warm temperatures, rates of vector-borne diseases (e.g., lyme disease, West Nile virus, and dengue), and water-related illnesses will likely increase.

To sustain healthcare capabilities, Southeast TX should incorporate cold weather threats into their planning, based on what hospitals and communities experienced during winter storm Uri. Health impacts from extreme cold weather can include frostbite and hypothermia and worsen existing conditions (e.g., cardiovascular, respiratory, cerebrovascular, and diabetes-related diseases). At-risk individuals need access to warm spaces, blankets, adequate food, and potable water. Indirect injuries and deaths linked to extreme cold temperatures can also occur and may include exhaustion from shoveling snow, carbon monoxide poisoning and fires from use of inappropriate heat sources, transportation barriers impacting access to care, increasing medical emergencies, or inhibiting staff ability to commute to work (e.g., blocked or icy roads). Protecting water, oxygen, and other systems at hospitals from freezing are key mitigation activities. Water and sanitation systems in the community may be vulnerable to cold damage and cause contamination or loss of services affecting many sectors of the population including dialysis patients.

The increased frequency and intensity of adverse weather events in Southeast TX may also have specific negative effects on the region's healthcare systems. Hospitals and EDs can quickly become overwhelmed by patient surges due to traumatic injuries caused by severe storms (such as hurricanes or

Related ASPR TRACIE Resources:

[Going with No Flow: Coping with Hospital Water Supply Issues](#)

[Healthcare System Recovery Timeline: A White Paper for Texas](#)

[Major Hurricanes: Potential Public Health and Medical Implications](#)

[Managing the Storm After the Storm: Healthcare in TX Recovers from Severe Winter Weather](#)

unexpected winter storms), exacerbation of chronic medical conditions, at-risk residents seeking medical assistance, and decreased healthcare staffing levels.

Severe weather events may also create patient evacuation challenges. Multiple hospitals in a region may need to evacuate simultaneously, creating surges and significant patient tracking challenges. Hospitals may also be relocated away from areas facing climate threats to facilities that are hardened against higher wind conditions, better protected from both heat and cold extremes, and capable of sustaining their own power generation and water supply for prolonged periods of time.



REGIONAL INSIGHT # 3: CENTRAL TENNESSEE

Overview of Central Tennessee Vulnerabilities to Climate Change

The TN climate, typically temperate, with warm summers and mild winters has a varied topography that leads to a wide range of climatic conditions. The flat plain of West TN is the warmest part of the state and is also the most active area for severe weather as it is susceptible to experiencing the remnants of tropical storms and hurricanes along the bordering areas.

Nashville, located in the northwestern portion of the Central Basin, has a generally mild climate ranging from 38 to 80 degrees Fahrenheit, and hot summer days averaging around 100 degrees Fahrenheit. The area receives an average of 45 inches of rain per year but rarely experiences snow conditions.

Climate change has contributed to warming temperatures over the last 20 years in TN and an increase in the State's annual rainfall. Projections indicate that in the coming decades, climate change will reduce crop yields, threaten aquatic ecosystems, and increase risks to human health. Flooding is also projected to become more frequent, however drought periods will also become longer. Although annual precipitation in TN has increased by about 5% since the first half of the 20th century, rising temperatures have caused water to evaporate, drying the soil and reducing the amount of rain runoff that enters rivers ([U.S. Environmental Protection Agency, 2016](#)).

In 2021, Nashville Mayor John Cooper's Sustainability Advisory Committee released a [Report on Metropolitan Government of Nashville and Davidson County's Climate Change Mitigation Action Plan](#) to identify recommendations and actions for Nashville to reduce its contributions to climate change, and ensure healthy and resilient communities. The report also assessed potential health benefits, such as better air quality, linked to increased solar energy and reducing carbon emissions.

In May 2010, Nashville experienced severe flooding, which caused over \$1.5 billion in economic damages. It brought the issue of global climate change to the forefront of the minds of city planners and residents.

Recent Events

More recently, in August 2021, nearly 17 inches of rain fell in Central TN in less than 24 hours, causing severe flash flooding and several deaths. It was the second major flooding in the state in 2021, with more than 20 fatalities. In March 2021, sections of Nashville were engulfed by torrential rainfall that killed at least four people ([Hersher, 2021](#)).

“Although rainfall during spring is likely to increase during the next 40 to 50 years, the total amount of water running off into rivers or recharging ground water each year is likely to decline 2.5 to 5 percent, as increased evaporation offsets the greater rainfall. Droughts are likely to be more severe, because periods without rain will be longer and very hot days will be more frequent” ([U.S. Environmental Protection Agency, 2016](#)).

Related ASPR TRACIE Resources:

[After the Flood: Mold-Specific Resources](#)

[Going with No Flow: Coping with Hospital Water Supply Issues](#)

Central Tennessee Climate Change Impacts on Human Health and Healthcare Systems

Climate change in Central TN will continue to have negative effects on human health and healthcare systems. One of the main climate change concerns will be hotter temperatures. As noted previously in this document, increased temperatures will cause people to become more vulnerable to dehydration, heat exhaustion, edema, syncope, heatstroke, hyperthermia, and acute cerebrovascular accidents (contributing to thrombogenesis). Hotter temperatures can also exacerbate existing medical conditions, such as chronic pulmonary disease, cardiac conditions, kidney disorders, and psychiatric illness. At-risk populations, including children, communities of color, low-income communities, immigrant populations, the elderly, and people with limited English proficiency may experience higher risks to these adverse events. It is also worthy to note that warmer temperatures increase ground ozone levels (a key element of smog), which can also aggravate lung disease (e.g., asthma), and increase the risk of premature death from heart or lung disease.

In addition, increased flooding and frequency of heavy precipitation are key concerns for this region. As previously identified in this document, flooding can cause the following: traumatic injury and death from drowning, preterm birth and low birth weight, and carbon monoxide poisoning related to power outages and inappropriate use of generators. Acute and chronic health issues may be exacerbated due to subsequent mold and other environmental issues, loss of housing, and poor living conditions. Increased rainfall may also increase the rates of vector-borne diseases (e.g., Lyme disease, West Nile virus, and dengue) and water-related illnesses.

Healthcare systems in Central TN will also be negatively impacted due to these adverse weather events. Hospitals and EDs can quickly become overwhelmed by a surge of patients requiring medical care due to traumatic injuries caused by severe storms (such as those causing flooding), and exacerbations of chronic medical conditions as well as at-risk citizens seeking assistance. In addition, adverse weather events can lead to a shortage of available healthcare workers if they are personally impacted by the disasters and are unable to come to work.

Hospitals and other healthcare facilities may be required to evacuate some or all patients or close completely. Multiple hospitals in a region may have to evacuate simultaneously, creating surges and significant patient tracking challenges. For future planning purposes, hospitals may have to be relocated away from areas of inundation threat. They will also need to be hardened against adverse events, and capable of their own power generation and water supply for prolonged periods.

Appendix A: Cited Resources List

The following resources (listed alphabetically) were cited in this document. ASPR TRACIE published a more comprehensive [Climate Change and Healthcare System Topic Collection](#) in 2022.

Agency for Toxic Substances and Disease Registry. (2021). [CDC/ATSDR Social Vulnerability Index](#). Centers for Disease Control and Prevention, U.S. Department of Health and Human Services.

The CDC/ATSDR Social Vulnerability Index (CDC/ATSDR SVI) uses 15 U.S. census variables to help local public health officials and emergency response planners meet the needs of socially vulnerable populations in emergency response and recovery efforts.

ASPR TRACIE. (2022). [Hospital Evacuation during a Wildfire and Pandemic: Avista Adventist Shares their Experience](#).

On December 30th, 2021, healthcare workers at Centura Health's Avista Adventist Hospital were managing a pandemic and planning for a winter storm. The hospital, which includes a large neonatal intensive care unit, was full, with less than 5% capacity. Unbeknownst to the staff working during that holiday weekend, the Marshall Fire was approaching the building, and would cause some of them to lose their homes while forcing the hospital to evacuate in under two hours. ASPR TRACIE met with five subject matter experts to learn more about their experiences, challenges, and lessons learned.

ASPR TRACIE. (2021). [Disasters and Healthcare Disparity Topic Collection](#).

The resources in this Topic Collection highlight considerations, factors, and lessons learned from a variety of natural and human-caused disasters and provide guidance for healthcare practitioners who are committed to addressing healthcare disparity.

ASPR TRACIE. (2019). [Hazard Vulnerability/Risk Assessment Topic Collection](#).

The resources in this Topic Collection highlight best practice resources related to hazard vulnerability analysis and risk assessment.

ASPR TRACIE. (2020). [Healthcare System Preparedness for Secondary Disasters during COVID-19](#).

This ASPR TRACIE technical assistance response discusses COVID-19 and secondary disasters, particularly as it pertains to health and medical considerations and need for facilities and communities to shelter-in-place or evacuate during disasters (e.g., hurricanes, tornadoes, and wildfires) while requiring maintaining social distancing practices.

ASPR TRACIE. (2021). [Managing the Storm After the Storm: Healthcare in TX Recovers from Severe Winter Weather](#).

Michael Wargo (HCA Healthcare), Scott Cormier (Medxccl), and Toni Carnie (HCA Houston Healthcare Tomball) share how a rare winter storm, extreme cold, and unplanned power outages affected utilities—particularly water and water pressure—in healthcare facilities throughout Texas.

ASPR TRACIE. (2018). [Tips for Retaining and Caring for Staff after a Disaster](#). U.S. Department of Health and Human Services, Office of the Assistant Secretary for Preparedness and Response.

This tip sheet provides general promising practices—categorized by immediate and short-term needs—for facility executives to consider when trying to retain and care for staff after a disaster.

Cal Fire. (2022). [Top 20 Largest California Wildfires](#).

This chart provides a list of the top 20 largest wildfires that occurred in California's history. It provides the fire name and cause, date, county where the fire occurred, number of acres burned, number of structures damaged, and the number of fatalities.

California Air Resource Board. (2021). [Camp Fire Air Quality Data Analysis](#).

This resource provides data on the air quality and other impacts from the 2018 Camp Fire.

Centers for Disease Control and Prevention. (2021). [Climate Effects on Health](#).

This webpage contains links to information on the national health effects of climate change on human health, and the various impacts faced regionally.

Centers for Disease Control and Prevention. (2022). [One Health Homepage](#).

This webpage provides information about One Health, which has been defined by the CDC as a “collaborative, multisectoral, and transdisciplinary approach—working at the local, regional, national, and global levels—with the goal of achieving optimal health outcomes recognizing the interconnection between people, animals, plants, and their shared environment.”

Centers for Disease Control and Prevention, Climate and Health Program. (2020). [Preparing for the Regional Health Impacts of Climate Change in the United States](#).

This report addresses the multitude of health impacts that climate change will have on the various regions of the U.S. It is based on the Fourth National Climate Assessment (NCA4). It also describes actions taken by the Centers for Disease Control and Prevention Climate and Health Program's health department partners to prepare for and respond to climate change in their communities.

City of Houston. (2021). [Houston Climate Impact Assessment 2.0: Understanding Houston's Past and Future Climate and What it Means for You](#).

This assessment report helped identify how future temperature and precipitation is expected to change in the greater Houston area through 2100. Specific indicators were used to assess the impacts, including the estimated likelihood and frequency of high intensity events (e.g., droughts, heavy rainfall, and heat waves), in addition to more chronic stressors (e.g., the annual average temperature, and number of hot days with temperatures above 100 degrees Fahrenheit).

Crimmins, A.R., Balbus, J., Gamble, J.L., et al. (2016). [The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment](#). U.S. Global Change Research Program.

This assessment provides an in-depth description of climate change impacts and associated health outcomes. The following topics are discussed: climate change and human health; temperature-related

death and illness; air quality impacts; extreme events; vector-borne diseases; water-related illness; food safety, nutrition, and distribution; mental health and well-being; and population of concern.

Deitchman, S.D., Kirsch, T.D., Auerbach, P.S., et al. (2021). [Climate Resilience: It is Time for a National Approach](#). Health Security.

This article addresses how climate-related disasters impact human health in two ways: they can directly cause illness, injury, increased mental health trauma, and loss of life (e.g., a hurricane or other extreme weather event); and indirectly affect population health and disrupt living conditions via damage to critical infrastructure, public services, and economic systems (e.g., as a secondary result of an extreme weather event).

Guenther, R., and Balbus, J. (2014). [Primary Protection: Enhancing Health Care Resilience for a Changing Climate](#). U.S. Department of Health and Human Services.

This 86-page document is a guide and toolkit designed to assist healthcare providers, design professionals, policymakers, and others with roles and responsibilities in assuring the continuity of quality health and human care before, during, and after extreme weather events. It is focused on healthcare infrastructure resilience to climate change impacts as manifested primarily by extreme weather events.

Hersher, R. (2021). [The Floods in Tennessee Aren't Freak Accidents. They're a New Reality](#). NPR.

The author addresses how climate change has impacted Tennessee and describes the rain and deadly flash flooding incidents that inundated central Tennessee in 2021.

Intergovernmental Panel on Climate Change. (2022). [Climate Change 2022: Impacts, Adaptation and Vulnerability](#).

This report is the sixth assessment report developed by the Intergovernmental Panel on Climate Change. It provides current and future implications for the negative effects of climate change on the physical and mental health. It includes observed and projected climate change impacts and risks, adaptation measures and enabling conditions, and conditions for climate resilient development.

Johns Hopkins Bloomberg School of Public Health, and Trust for America's Health. (2020). [Climate Change & Health: Assessing State Preparedness](#).

This report assessed all 50 states and the District of Columbia on their level of preparedness for the health effects of climate change and found a great deal of variation in their preparedness to protect residents' health. Some states have made significant preparations, while others have barely begun this process.

Kacik, A. (2019). [California Hospitals Adjust to a New Normal as Fires Rage](#). Modern Healthcare.

This article discusses how California hospitals are facing the reality of increased black outs, evacuations and wildfires which caused hospitals to increase preparedness activities in response to natural and man-made threats.

Mullins, J.T., White, C. (2019). [Temperature and Mental Health: Evidence from the Spectrum of Mental Health Outcomes](#). Journal of Health Economics. 68:102240.

The authors of this article explain the data in their study, which found a direct linear relationship between temperature and incidence of suicide in the U.S.

Nashville Mayor John Cooper's Sustainability Advisory Committee. (2021). [Report on Metropolitan Government of Nashville and Davidson County's Climate Change Mitigation Action Plan](#).

The report identifies recommendations and actions for Nashville to reduce its contributions to climate change, as well as ensure a health and resilient future for the community. The report also identifies potential health benefits, such as better air quality by increasing solar energy and reducing carbon emissions.

National Aeronautics and Space Administration (NASA). (2017). [Natural and Manmade Hazards in the State of Texas](#).

The resource describes how monitoring from space can help assess the natural and manmade hazards in the State of Texas.

National Council of State Boards of Nursing, Inc. (2022). [Nurse Licensure Compact \(NLC\)](#).

This webpage provides information on the NLC, which increases access to nurses while maintaining public protection at the state level. Under this compact, nurses can practice in other NLC states and are not required to obtain additional licenses.

National Oceanic and Atmospheric Administration. (n.d.). [What is Ocean Acidification?](#) (Accessed 2/15/2022.)

This brief webpage provides an overview of ocean acidification and the negative impacts that it is having on the world's oceans, coastal estuaries, and waterways.

National Oceanic and Atmospheric Administration, National Severe Storms Laboratory. (n.d.). [Severe Weather 101: Types of Damaging Winds](#). (Accessed 2/15/2022.)

This brief webpage provides definitions and information on the various types of severe winds.

Pierre-Louis, K., and Schwartz, J. (2021). [Why Does California Have So Many Wildfires?](#) New York Times.

This article describes how scientist have designated two wildfire seasons in California due to lack of rainfall, increase temperatures, and Santa Ana Winds.

Reidmiller, D., Jay, A., Avery, C.W., et al. (2018). [Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II](#). U.S. Global Change Research Program.

This report to Congress evaluates the effects of global change on the environment including, agriculture, energy, land and water resources, transportation, and human health. It outlines the projected risks identified by researchers and provides examples of actions that can be taken to reduce risk, increase resiliency, and improve sustainability.

Rogan, E., and Lewis, J. (2020). [Rural Health Care: Big Challenges Require Big Solutions](#). American Hospital Association.

This article identifies the challenges that healthcare systems face in rural America, and action steps to help resolve some of those issues.

Rosenthal, A., Stoker, E., and Haar, R.J. (2021). [Health and Social Impacts of California Wildfires and the Deficiencies in Current Recovery Resources: An Exploratory Qualitative Study of Systems-level Issues](#). PLOS ONE. 0248617

This article describes a qualitative study on health and social service workers to determine the cause and effect of health and social impacts from wildfires. Factors related to the Tubbs wildfire included contaminated drinking water containing Benzene, which is a cancer agent. Mental health issues and trauma correlated to interpersonal violence. Hospitals and emergency departments were often the only medical facilities operating with the healthcare workforce being impacted by personal loss to include 210 physicians and healthcare workers who lost homes and unable to work impacting the hospital during the wildfire.

Sawyer, R.C., Desalvo, B., and Gottschalck, A. (2022). [New Census Bureau Data Product Measures Communities' Social Vulnerability and Equity](#). U.S. Census Bureau.

This tool provides data on communities' social vulnerability and equity. It includes maps and tables of the most up-to-date demographic characteristics including health insurance, access to transportation, disability, race/ethnicity, languages, ages, and the Census Tract.

Simons, E. (2017). [How Extreme Heat Caught San Francisco By Surprise Over Labor Day Weekend](#).

The author of this article discusses the Labor Day weekend heat wave that the Bay Area experienced in 2017. Downtown San Francisco peaked at 106 degrees by that Friday afternoon, which was recorded as the hottest on record in 143 years. This event resulted in three fatalities and 50 hospitalizations for heat-related illness in the city.

Smith, A.B. (2021). [2020 U.S. Billion-dollar Weather and Climate Disasters in Historical Context](#). NOAA.

This webpage explains NOAA's National Centers for Environmental Information 2020 update to its [Billion-dollar Disaster Report](#). The report describes what communities across the U.S. experienced in 2020 was a historic year of extremes.

Sonoma County Ag + Open Space, and The Sonoma County Watershed Collaborative. (2019). [2017 Sonoma Complex Fires](#).

This document describes the 2017 Sonoma Complex Fire (consisting of the Nuns, Tubbs, and Pocket Fires) that burned over 87,000 acres of Sonoma County's lands. On the night of October 8, 2017, an unprecedented wind event led to one of the worst wildfires in Sonoma County history and led to almost three weeks of fires burning in the area.

State of California Government. (2021). [California's Fourth Climate Change Assessment](#).

This assessment is part of California's comprehensive strategy to address climate change by identifying the gaps that will bolster actions by decision-makers at the state, regional, and local levels to protect and build resilience in California's communities, infrastructure, and environment.

State of California Government, California Department of Forestry and Fire Protection (CAL FIRE). (2021). [Incidents Overview Homepage](#).

This web page provides detailed information about all fire incidents in the State of California.

The Lancet. (2015). [Health Professionals: Be Prepared for Heatwaves](#). 386(9990): 219.

This editorial provides an overview of factors and issues to consider during heat waves. It provides links to the World Health Organization and World Meteorological Organization report, Centers for Disease Control and Prevention guidance, and other applicable webpages.

The United States Census Bureau. (2021). [Community Resilience Estimates for Equity Dashboard](#).

The Community Resilience Estimates (CRE) program provides metrics of social vulnerability at the local neighborhood-level in the U.S. to the impacts of disasters, including COVID-19. The program helps provide context as to why certain areas may be socially vulnerable or resilient. This dashboard combines data from the 2019 Community Resilience Estimates and the 2015-2019 American Community Survey 5-year estimates.

Thompson, R., Hornigold, R., Page, L., & Waite, T. (2018). [Associations Between High Ambient Temperatures and Heat Waves with Mental Health Outcomes: A Systematic Review](#).

This study describes the mental health effects of high ambient temperatures and heat waves, determines whether heat-related morbidity and mortality are increased among people with known mental disorders and identifies knowledge gaps to inform targeting of future research.

U.S. Department of Health and Human Services. (2021). [2021 Climate Action Plan](#).

This document provides guidance on how the U.S. Department of Health and Human Services can work to protect the health of Americans from climate change-related threats. It addresses actions to help individuals and communities at greatest risk from these threats.

U.S. Department of Health and Human Services. (n.d.). [Ensuring Language Access and Effective Communication During Response and Recovery: A Checklist for Emergency Responders](#).

This two-page document provides recommendations and action steps for emergency responders working with interpreters during disasters.

U.S. Department of Health and Human Services. (n.d.). [Healthy People 2030: Social Determinants of Health](#). (Accessed 2/15/2022.)

This resource provides information on the five domains of Social Determinants of Health, which are: economic stability, education access and quality, healthcare access and quality, neighborhood and built environment, and social and community context.

U.S. Department of Health and Human Services emPOWER Program. (2020). [HHS emPOWER Map](#).

The HHS emPOWER Map provides monthly de-identified totals of Medicare claims submitted for one or more of the fourteen types of life-maintaining or saving electricity-dependent durable medical and assistive equipment (DME) and certain implanted electricity-dependent cardiac devices, at the national, state, territory, county, and ZIP Code levels. Users have the ability to create unique aggregations by geography and export the data, as well as the ability to access historical HHS emPOWER Map datasets for further analysis. When combined with real-time severe weather and hazard maps, the HHS emPOWER Map gives communities the power to anticipate, plan for, and address the needs of this population prior to, during, and after an incident, emergency, or disaster.

U.S. Department of Health and Human Services' Sustainable and Climate Resilient Health Care Facilities Initiative. (2016). [Climate Resilient Health Care Facilities Toolkit](#).

This online toolkit can help healthcare facility planners learn more about implementing best practices in climate resilience. It is based on a framework composed of the following five elements: Climate Risks and Community Vulnerability Assessment; Land Use, Building Design, and Regulatory Context; Infrastructure Protection and Resilience Planning; Essential Clinical Care Service Delivery Planning; and Environmental Protection and Ecosystem Adaptations.

U.S. Department of Justice. (2007). [Americans with Disabilities Act Checklist for Emergency Shelters](#).

This document provides guidance and checklists that can help state and local government planners ensure that emergency shelters are compliant with the Americans with Disabilities Act.

U.S. Environmental Protection Agency. (2016). [Climate Change Impacts by State](#).

This website provides a breakdown of climate impacts by U.S state and territory. Additional resources include impact data broken down by region and sectors such as agriculture, energy, transportation, and water.

U.S. Environmental Protection Agency. (2021). [Climate Change Indicators in the United States](#).

This website provides information on the indicators related to the causes and effects of the various climate change threats.

U.S. Federal Emergency Management Agency. (2010). [Guidance on Planning for Integration of Functional Needs Support Services in General Population Shelters](#).

This document provides guidance for state emergency managers and shelter planners to help them meet the requirements of access and functional needs in general population shelters.

U.S. Geological Survey. (n.d.). [What is a sinkhole?](#) (Accessed 2/15/2022.)

This webpage provides an overview of sinkholes including information on what they are and how they are formed. Links to additional related information are also included.

World Meteorological Organization. (2021). [WMO Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes \(1970–2019\)](#).

This report provides information on the impacts from weather, climate, and water extremes globally from 1970 to 2019 based on disaster data from the Emergency Events Database.

Young, S., Balluz, L., and Malilay, J. (2004). [Natural and Technological Hazardous Material Releases During and After Natural Disasters: A Review](#). (Abstract only.) *Sci Total Environ.* 322(1-3):3-20.

This article addresses how natural-technologic events pose unique environmental and human hazards. These events are caused by natural events that trigger technologic malfunction and consequently release hazardous materials.

Young, S., Mallory, B., and McCarthy, G. (2021). [The Path to Achieving Justice40](#). The White House.

This website provides information on President Joe Biden's [Justice40 Initiative](#), which "is a whole-of-government effort to ensure that Federal agencies work with states and local communities to make good on President Biden's promise to deliver at least 40 percent of the overall benefits from Federal investments in climate and clean energy to disadvantaged communities."

Appendix B: Acknowledgments

This document was developed by ASPR TRACIE, in collaboration with ASPR TRACIE Senior Editor, John Hick, MD, Hennepin Healthcare. The following subject matter experts contributed to/ reviewed this document (listed alphabetically):

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