CLIMATE CHANGE, EXTREME WEATHER EVENTS, AND IMPACTS ON PUBLIC HEALTH

EXECUTIVE SUMMARY

In the aftermath of extreme weather events, the arising public health challenges are an often-underestimated consequence. Science has long agreed that the case of increasing extreme weather is mediated by changes in overall global temperatures over time. This is contributing to more frequent and intense extreme weather events. In addition to the potential for massive destruction of property and economic losses, these events also bring cascading consequences on human health and property which need to be addressed for complete recovery to occur. These dangers become the responsibility of public health stakeholders, tasked with their mitigation.

Globally, certain geographic factors such as elevation, coastal proximity, and urbanization influence vulnerability. Through situational responses and our work with our partners, Healthcare Ready has seen how the rising of global temperatures directly and indirectly contributes to rising sea levels, a phenomenon which, in ways similar to extreme weather, presents challenges to health security and increases overall threats to affected residents' well-being. Still, many additional impacts which are beyond our scope exist and pose very real threats which will continue to be felt in the future.

A few key populations are of concern in the context of vulnerability to extreme weather; the elderly, minorities, and the poor. These vulnerable populations tend to reside in areas least prepared for these events or lack the physical capacity to endure the impact compared to the general population. Identifying these populations is vital to creating resilience to extreme weather events.

Healthcare Ready remains dedicated to addressing the need to build resilience to protect public health through multilateral approaches including infrastructure, patient care, and community resources and development. We are cognizant of the ongoing cooperation this effort requires and are invested in working with our partners to achieve our goal of a resilient health system. While this document provides information on our perspective at the time of writing, this is not intended to be comprehensive of all the healthcare impacts of a changing climate or the work of the whole industry to remedy this .

Due to the interconnected nature of so many of these events and their downstream impacts, a full understanding of these concepts can be viewed as a moving target. To address this target, deeper research which expands on the concepts outlined in this document is required to help us understand the implications of climate change and extreme weather on public health.

KEY FINDINGS

This paper serves to provide a high-level outline of the ways in which climate change not only leads to more extreme weather events but is also likely to cause them to occur with higher frequency. These weather events are intricately linked to many aspects of public health, often causing significantly disruption and threats to life and property. Stakeholders in every role of healthcare must collaborate to develop resilience to these vulnerabilities. With that, our findings are summarized as follows:

- Extreme weather causes significant impacts to public health, both directly (immediate hazards and damages associated with the event) and indirectly (through disruption of health supply chain and services).
- Anthropogenic climate change is likely to drive increases in extreme weather events, both in frequency and severity. This, in turn, will have amplified effects on public health.
- Certain populations, such as infants and young children, those with chronic care needs, disabled individuals and those with access and functional needs, ethnic minorities, the elderly, and those residing in certain regions are more susceptible to severe weather and the subsequent health impacts.
- Community-level engagement is essential to developing resilience, especially in the face of a growing risk from climate change driven severe weather.
- Establishing resilience to severe weather is a difficult task, requiring the coordination of multiple stakeholders with uniquely different needs. Private-Public partnerships are essential in allowing the private sector to work with public agencies and establish effective preparedness plans and response measures.

INTRODUCTION

The last two hurricane seasons served as a costly and deadly reminder of the very real public health impacts which severe weather often brings. The 2017 year was well above average, with four major hurricanes among the seven tropical systems to impact the US and Puerto Rico. With humanitarian crises following in their wake and a death toll in the thousands, the catastrophic impact of these storms on human health is unprecedented *(1,2).* In September and October of 2018, more hurricanes brought record-breaking flooding and catastrophic damage to areas of the Gulf Coast, Southeastern US, and the US Northern Mariana Islands, killing dozens *(3,4)*.

In addition to the hazardous environments caused by the high winds and flooding associated with hurricanes, other forms of severe weather bring dangerous challenges like temperature extremes, power outages, economic destruction, and strain on food and medical supply chains. Questions about a changing climate and how to build resilient communities with adequate public health infrastructure to respond to these events are priorities for Healthcare Ready and our partners.

Not only can extreme weather events be indisputably attributed to a rise in global temperatures, but the public health preparedness community has started to understand the dynamic health challenges which present themselves during and after such disasters. Extreme weather events present public health challenges, unique to the event type and the locations impacted. For example, the threat of vector-borne diseases coincides with flooding *(5)*, and the effect of an urban heat island is of concern during an extreme heat event, both leading to increases in morbidity and mortality. These threats disproportionately impact certain vulnerable populations, such as the very young and elderly, low-income communities, and immunocompromised individuals. Accordingly, it is essential that these, and other at-risk populations, are specifically addressed in emergency plans and that health infrastructure is strengthened in such a way that protects all populations.

As seen again and again, extreme weather events cause serious health problems for affected populations for a variety of reasons – chronic health conditions can be exacerbated, and new, acute injuries can be caused. At the same time, the health infrastructure where affected patients may seek care could be impacted. Health systems and healthcare supply chains are vulnerable to a surge in patients, loss of power or fuel supplies, displacement of large numbers of people, and the destruction or blockage of roads and civil infrastructure – all of which are closely associated with extreme weather.

Addressing these risks to quality healthcare continuity must be a major consideration in guiding the development of resilient. Although recent events have created a sense of urgency around these issues, the questions are not new, and their answers have been the subject of scientific research for decades.

As the effects of change became more visible, it is imperative that influential voices among the public health community converge to recognize and mitigate the threats increasing extreme weather events pose to public health. When considering the future of healthcare systems, consequences from climate change and extreme weather events create a reality with very real impacts on human health and property which must be addressed.

This white paper seeks to provide a high-level overview of climate change-driven extreme weather events, the communities/populations most impacted by these events, and the public health impacts which follow.

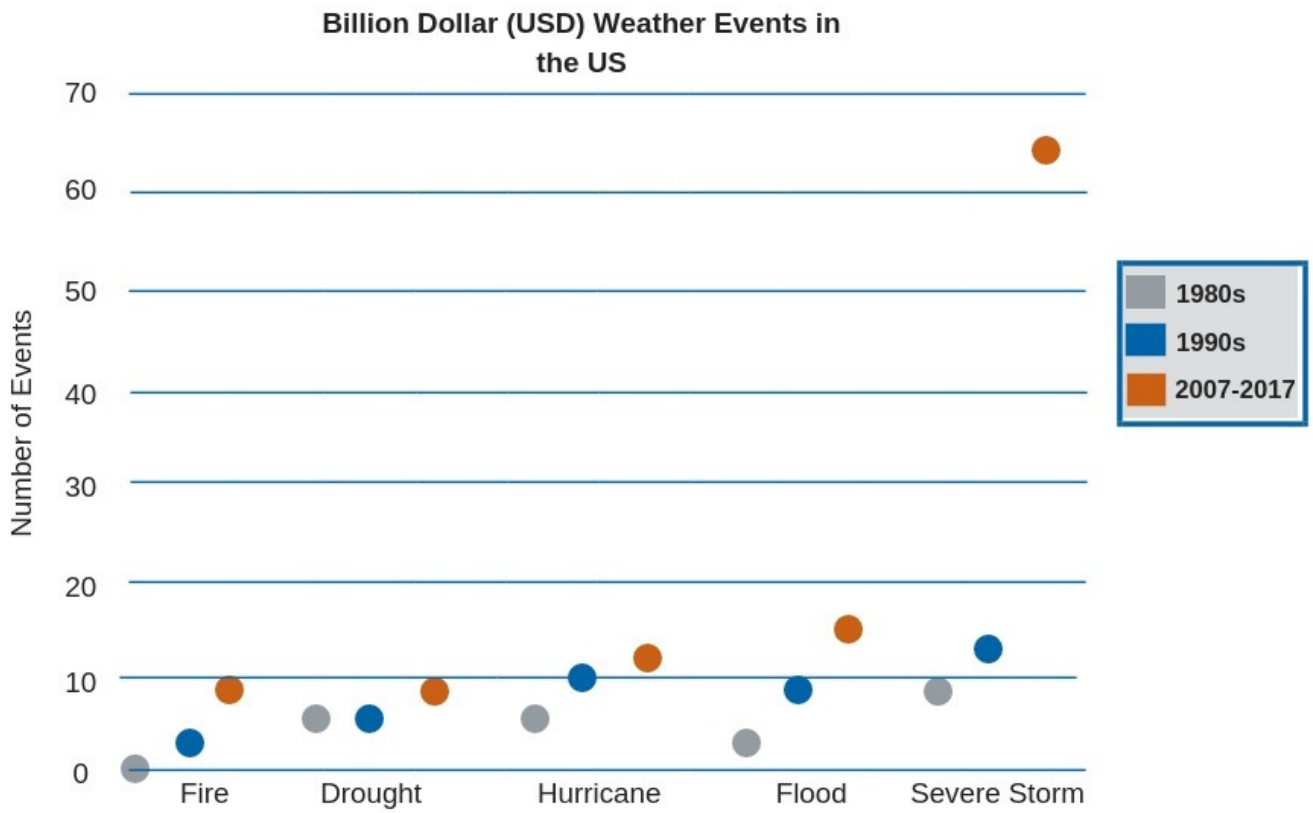

Figure 1. Graphical breakdown of billion-dollar (USD) weather events by decade and type *(6)*.

EXTREME WEATHER HITS VULNERABLE POPULATIONS THE HARDEST

Some geographic locations are inherently more susceptible to disaster than others, based on factors like weather pattern influences and proximity to oceans. Additionally, certain groups of people may be disproportionately impacted by extreme weather and the consequential health impacts for a number of reasons, most of which are socioeconomic or based on where they live *(7)*. Identifying populations which are more susceptible is necessary in making sure they are protected from unjust burden. Such assessments are often complicated, requiring input from a variety of sources, such as community member accounts, risk assessment results, and analyses of demographics.

Vulnerable populations – There are certain factors which make distinct populations particularly vulnerable to the impacts of extreme weather. Important populations from a public health standpoint include:

- **Infants and young children:** Far more susceptible to risks from their environment, children require adequate nutrition and safe housing to ensure their mental and physical development can occur properly. Heat can be of serious concern, with their immature and developing immune systems rendering them considerably more vulnerable to diseases *(8)*. Children are also more likely to experience long-term effects if they encounter hazardous toxins and chemicals which may permanently impact their physical or cognitive development *(9)*. Floods frequently overrun sewage systems and storm drains, rupture pipes, and cause leaks from factories or manufacturing facilities, all of which are sources for these hazardous chemicals and byproducts which may end up contaminating flowing or standing waters in the wake of a severe storm *(10).*

- **Individuals with chronic care needs:** Those with pre-existing medical conditions typically require, at the bare minimum, a steady stream of prescription medicines to replenish those being taken regularly *(11).* The dependence of these patients on daily or weekly medications changes their dependence on the health system, namely pharmacists and other dispensers. During and immediately following a disaster, access to these services are likely to be disrupted.

  Lack of electricity presents challenges in keeping temperature-sensitive products viable (such as vaccines and insulin)*(12)* and can cause challenges for certain patients, such as those with asthma or other breathing conditions, dependent on electric-powered devices (e.g. nebulizers)*(13).*

Individuals dependent on local health facilities (such as end-stage renal disease patients requiring dialysis treatments multiple times a week) can be in danger of not being able to access these services due to transportation challenges, impacted facilities, and more. These situations can quickly turn into an emergency for such patients. Pre-existing conditions can also be exacerbated by the effects of extreme weather events, such as lung or heart disease patients being impacted by air quality during a heat wave *(14)*.

- **Disabled persons and those with access and functional needs:** Disabled persons can be dependent on family or friends or an in-home care provider to assist them *(15).* Flooding or other destruction of roadways can make it impossible or dangerous for a caregiver to come visit a disabled patient, oftentimes leaving the patient without the care or medicine that they need. Individuals disabled from certain injuries, such as those to the spinal cord, are less able to sweat, and thus are prone to overheating far quicker than the general population *(16).*

- **Ethnic minorities:** A multitude of socioeconomic factors lead to ethnic minorities being more vulnerable to natural disaster . There are inherent cultural differences , language barriers, and other socioeconomic considerations which directly impact a populations' vulnerability to disaster situations. For instance, Hispanics and African Americans are less likely to have adequate medical supplies in their homes in case of an emergency *(17).* Minority populations also tend to have higher levels of distrust towards the government – a factor which can lead to them rejecting evacuation orders and other guidance from public health officials. One post-Katrina study, interviewing minorities who had resided in New Orleans before the storm and were being sheltered after the destruction, found that most actively questioned the competency of government officials and emergency responders at every level. The interviews revealed widespread and "profound" distrust for the government, questioning both the honesty of officials and first responders and the equity of their disaster response *(18).*

The racial disparity of Hurricane Katrina was stunning; the hardest hit Lower Ninth Ward neighborhood was 98% Black or African American at the time of the storm's landfall *(19)*. The disparities extended outside of this particular neighborhood as well. In the hardest hit areas, nearly one in three individuals were Black. Evacuation was likely difficult if not impossible for poor minority residents in these areas, as nearly 60% of poor Blacks lacked a vehicle, leaving them disproportionately more likely to "ride out" the impending storm despite mandatory evacuation orders *(20)*.

- **The elderly:** Elderly individuals specifically are more likely to suffer from chronic disease and depend on caregivers, often residing in nursing facilities. There are more than 6 million Americans aged 65 or older who require some form of in-person or long-term care in such facilities every year *(21).* Like any healthcare center, such nursing facilities require evacuation due to power outage or other impacts from extreme weather, leaving these elderly patients needing shelter, supplies, and, most importantly, continued care. Any of these may complicate the process of delivering their care, and all of which increase overall vulnerability to disaster. For instance, in the months following the landfall of Maria on Puerto Rico, the mortality rate for individuals aged 70 or above saw increases of nearly 30 percent, compared to the previous year's rate *(22).*

- **Geographic locations:** Certain regions of the US are at higher risk for extreme weather **(Figure 2)**. For example, the Gulf Coast states are increasingly threatened by rising sea levels, which brings more and more water into proximity to low lying coastal areas and provides opportunities for floods caused by hurricane storm surge to have severe and devastating impacts on critical health infrastructure. Other notable areas of concern include the Southwest US, which is susceptible to extreme droughts, and the large urban areas, vulnerable to extreme heat waves.

What Healthcare Ready Sees: Vulnerable Populations

Through working to connect patients to healthcare during and after disasters, Healthcare Ready regularly witnesses how vulnerable populations can be disproportionately impacted. Following Hurricanes Matthew and Irma, Healthcare Ready helped coordinate oxygen tanks for patients with chronic conditions in special needs shelters. Serving also as an advocate for prescription assistance programs, this work helps uninsured or underinsured patients receive needed refills they otherwise could not afford when displaced.

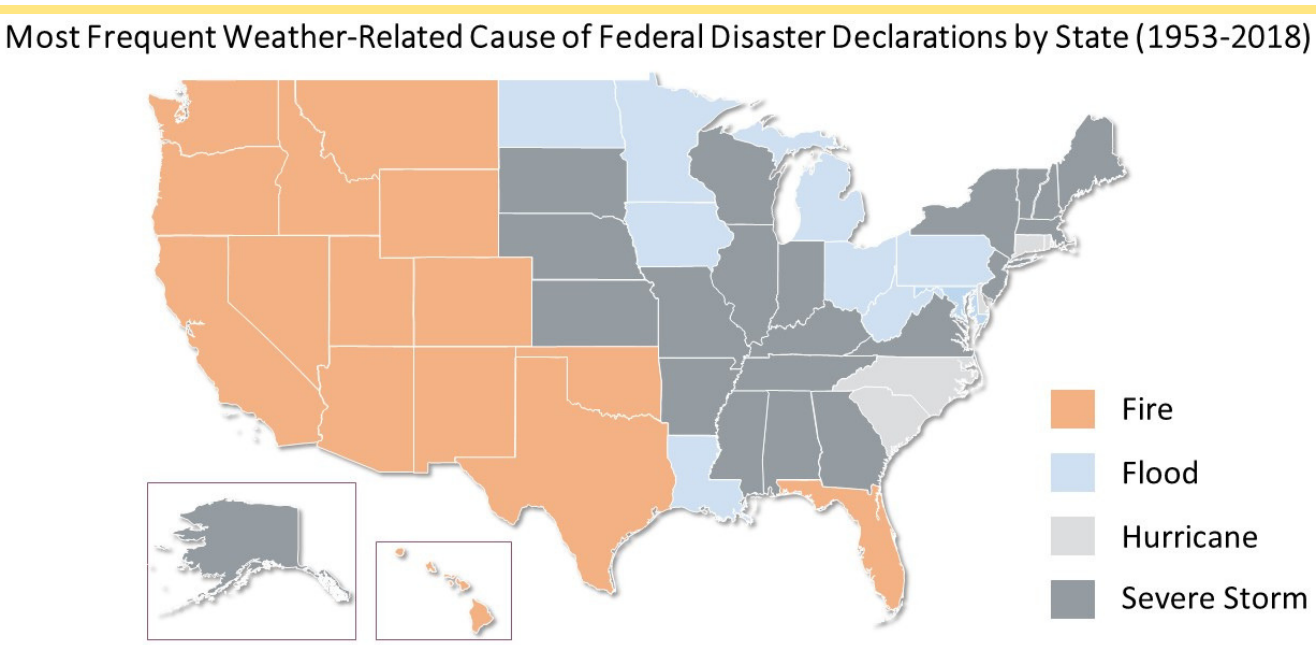

Figure 2. Map depicting the most frequent weather-related cause, by state, for Federal Disaster Declarations between 1953-2018 *(23).*

Disparities in care requirements complicate planning for severe weather

Development of comprehensive plans for health system resilience to extreme weather is complicated by differences in resource availability and needs of distinct demographics. Additionally, the medication and supply needs of diverse patients – for instance, the needs of patients with end-stage renal disease and those requiring chemotherapy – necessarily puts diverse supply and preparedness needs on healthcare providers. Establishing comprehensive preparedness plans that integrate the unique needs of distinct patient groups is a moving target for policymakers, especially regarding extreme weather preparedness.

These challenges are further compounded by the reality that preparedness is a shared responsibility – the Federal Emergency Management Administration (FEMA) and state and local emergency managers play an important role, but it also takes healthcare providers, patients, caregivers, and dozens of other invested stakeholders, including citizens.

The high cost of clean-up presents challenges

For individuals and families in the lowest socioeconomic classes, disaster cleanup is often synonymous with having high costs for debris removal and repairs. Recent Healthcare Ready polling data revealed that more than half Americans lack even basic emergency preparedness plans. These individuals, often without insurance and cash savings to assist with recovery are sometimes left without any other option but to return to their home in affected areas.

Those choosing to return to their homes which may have been damaged or destroyed face numerous dangers to their health. They may be subject to structurally unstable buildings, mold, chemicals, and other floodwater hazards while awaiting crews to inspect the homes (24). For example, without the ability to afford basic survival or emergency preparedness measures, these populations may risk drinking contaminated water, sustaining acute injuries which may become infected without proper wound care, and may be vulnerable to extremes in heat and cold without power. Persons of low socio-economic status are also less likely to be covered by health insurance, further convoluting their path to recovery after a weather disaster (25).

WEATHER IMPACTS ON PUBLIC HEALTH and PUBLIC HEALTH INFRASTRUCTURE

Extreme weather events from hurricanes to heat waves to strong thunderstorms can have enormous immediate and long-term effects on public health. Destruction of power and clean water services can expose affected populations to dangers such as harmful pathogens and live electrical wires. These events can also be damaging to other infrastructure, leaving lasting disruption to healthcare facilities, the healthcare supply chain, and civil infrastructure such as roads and bridges which are important in connecting patients to their healthcare.

Recent events underscore a "new normal"

2017 hurricane season

The devastating consequence severe weather can have on human health was felt by millions in the 2017 hurricane season. Between August and September of 2017, three major hurricanes – Harvey, Irma and Maria – formed east of the Lesser Antilles, all rapidly gaining strength and speeding westward towards the Caribbean and United States mainland.

Hurricane Maria would rank among the top four most devastating to hit the US. Hurricane Maria will also be remembered for causing a humanitarian crisis, depriving residents of Puerto Rico of consistent access to clean water, food, electricity, and healthcare for long durations after the hurricane made landfall (26). Despite the relatively low death tolls initially reported, studies conducted in the months after the storm determined that upwards of 5,000 deaths were likely attributed to Maria (27).

Combined, the Atlantic tropical cyclones of 2017 brought over $250 billion in damages, dwarfing even the infamous 2005 season which saw the likes of Hurricanes Dennis, Katrina, Rita, and Wilma make US landfall as major hurricanes of category 3 or higher (28).

With a death toll of 89 and a price tag of $128 billion, Harvey was the second costliest natural disaster in US history, following only Hurricane Katrina (29,30). Climatologists have addressed the role that high temperatures played in elevating Harvey into an unprecedented disaster which impacted the Houston area (31). For the entire winter preceding the 2017 hurricane season and through the time of Harvey's arrival, sea surface temperatures in the Gulf of Mexico remained very warm, never falling below 73°F (23°C) for the first time on record (32).

As sea surface temperatures rise, more ocean water evaporates into the atmosphere and creates instability aloft, precisely what was seen last summer in the Gulf. As Harvey entered this unusually warm region 400 miles southeast of Houston, it encountered sea surface temperatures 4 degrees above normal (33). This unusually warm water fueled Harvey's rapid intensification from a tropical depression into a Category 4 storm in under 48 hours **(Figure 3)**. The storm made landfall northeast of Corpus Christi and stalled, bringing nearly five days of torrential rain to the Houston area.

While the 2017 hurricane season in the Atlantic was well above average in every metric of activity **(Figure 4)**, it is unknown how big of an impact climate change may have on the formation and strength of tropical cyclones.

A 2017 report published by the US Government forecast that tropical cyclone frequency and intensity will increase in a commensurate way with global warming and rising sea-surface temperatures. Although this cannot be stated with absolute certainty due to lack of consistent historical hurricane data, the authors demonstrated moderate confidence in higher wind speeds among future storms (34).

What almost every climate scientist does agree on, however, is that tropical storms and hurricanes are trending towards being wetter. Higher rainfall amounts are more likely with these storms due to excess latent heat in the oceans. Furthermore, the risk of storm surge or coastal flood events is greatly increasing side by side with this phenomenon and sea-level rise (36). With the devastating potential of these storms on full display in the Caribbean and Gulf last year, steps must be taken to better prepare our health systems and ourselves in order to prevent a repeat of the humanitarian disasters of 2017.

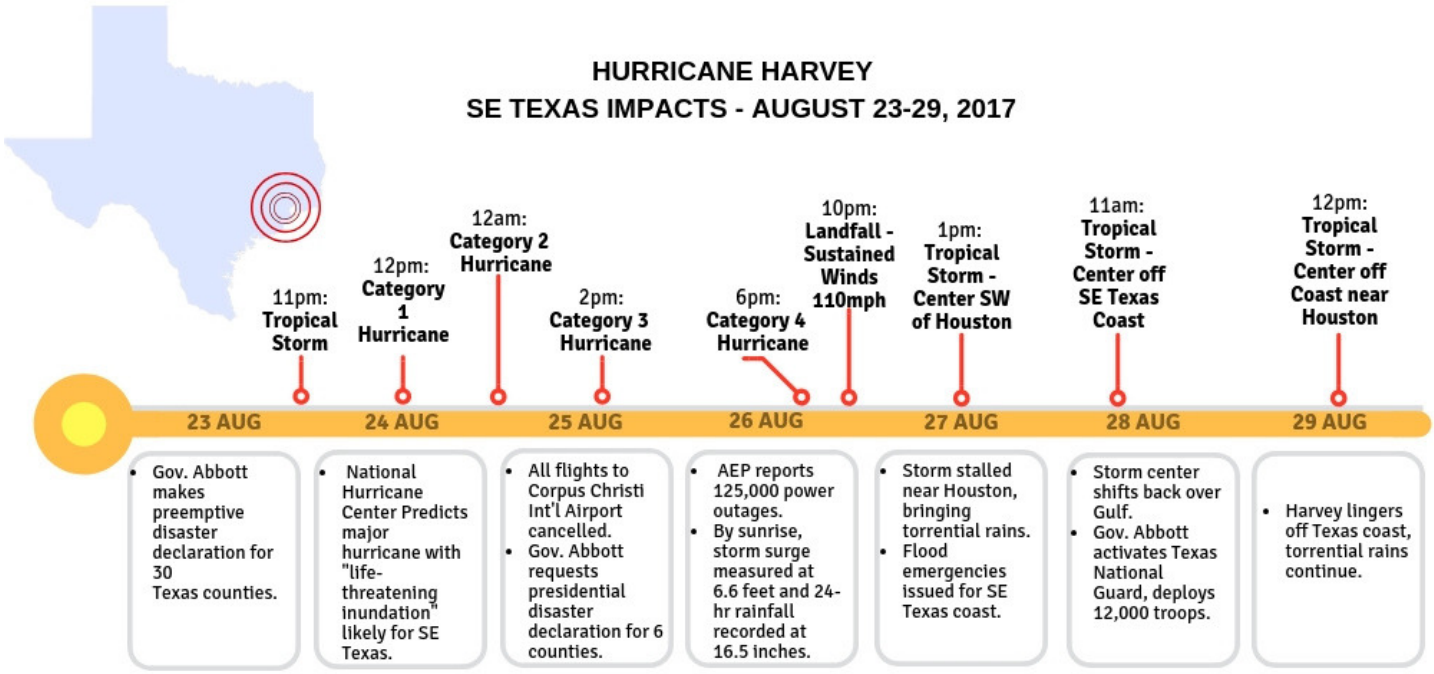

Figure 3. Hurricane Harvey timeline in the Gulf Coast *(35,36).*

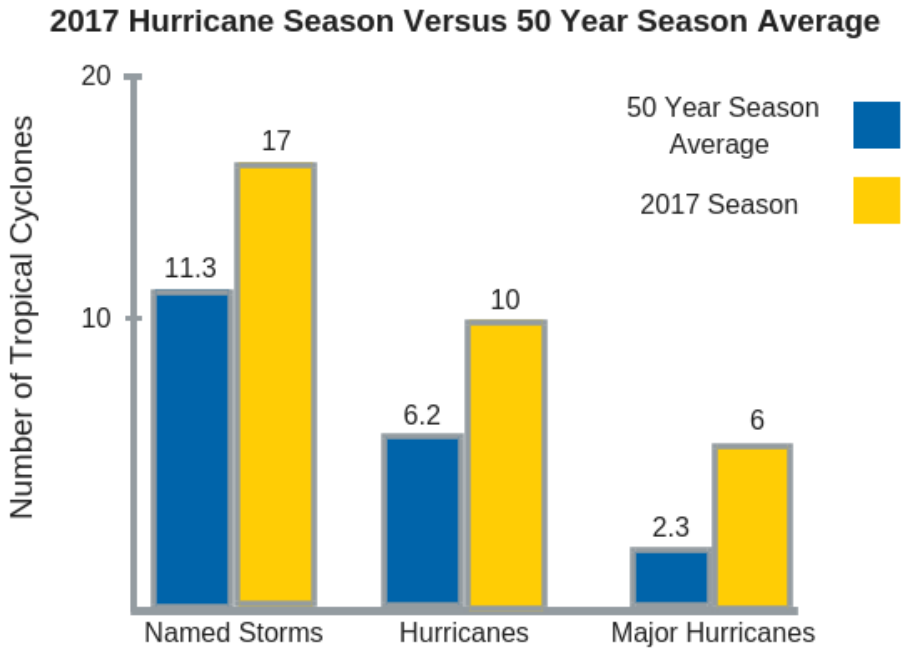

Figure 4. A chart comparing the above average 2017 hurricane season to historical averages gathered by the National Hurricane Center *(35)*.

Droughts, wildfires, and other extreme events

In addition to the devastating hurricane season of 2017, climate change-driven severe weather has directly impacted human health in many other ways. Notably, the state of California experienced a severe drought from 2011 to 2016, a consequence of the La Niña phase of the El Niño/Southern Oscillation (ENSO). The ENSO is a pattern of wind and oceanic temperature fluctuations which can bring drastic changes to weather in the continental US. Consequently, 100% of California was experiencing drought conditions of "severe" or worse by 2014 *(36)*. Droughts put food and water security at risk, a problem that disproportionately affects agricultural or indigenous communities. Severe droughts often increase the threat and intensity of widespread wildfires, which can cause harmful smoke pollution.

During the ENSO drought , wildfires such as the Soberanes fire raged, causing nearly $300 million in damage and destroying over 130,000 acres of land (37). These wildfires lead to smoke pollution, which can affect areas miles away from the flames. Those affected by the smoke can suffer a wide range of effects, from brief fits of coughing or irritation to aggravation of underlying conditions like asthma or lung and heart diseases (38).

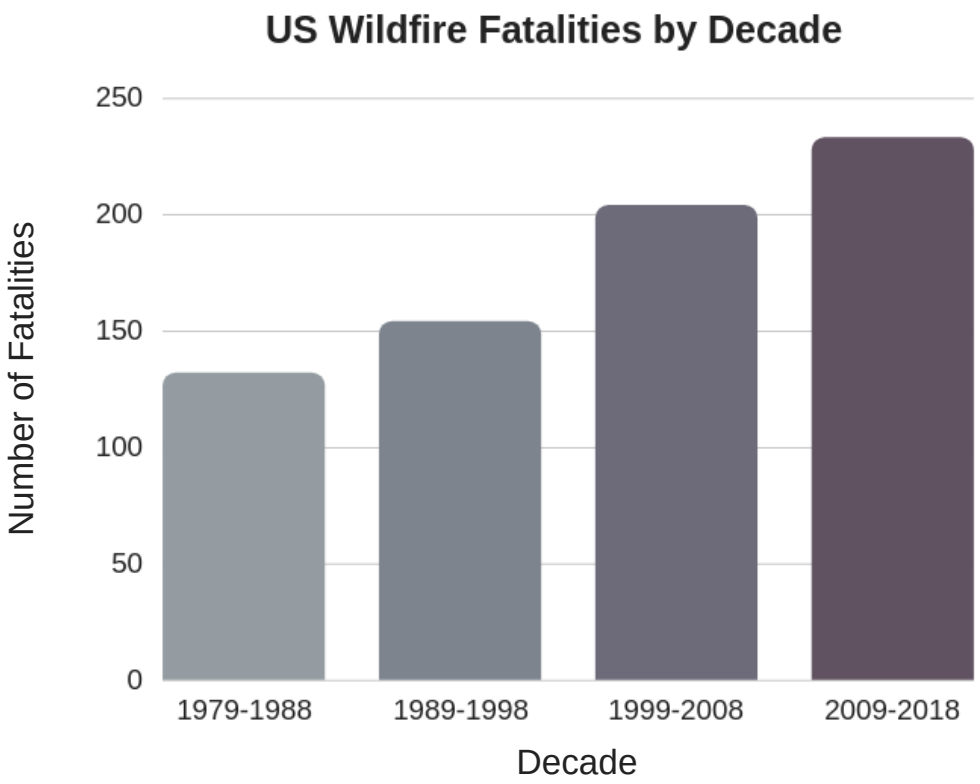

Figure 5. United States wildfire fatalities by decade, from 1979 - 2018. *(39,40)*.

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EXTREME WEATHER AND DISASTER RESPONSE IMPACTS

As global air and sea temperatures continue to rise, extreme weather events are expected to increase in both frequency and severity. Such events pose a serious threat not just to healthcare systems and public health, but the critical infrastructure systems on which they are dependent – transportation, power, telecommunications, water and more. Impacts that droughts, wildfires, and other events have on these systems can impact healthcare continuity when patient health needs may already be surging.

Infrastructure damage presents challenges

Blockage and destruction of roads, downing of power lines, and lingering debris or other hazards can create challenges to a response in many ways. For example, civil infrastructure disruption may physically block survivors' (including patients') or emergency responders' access to healthcare facilities. Floodwater inundation is also a concern, with flooded roads both blocking routes to health facilities as well as posing the threat of disabling or sweeping vehicles away. The electrical grid is an additional vulnerability, with many shelters or healthcare facilities requiring power for operational continuity.

These types of civil infrastructure disruptions can create a situation where the critical health infrastructure of an area is intact but may be otherwise inaccessible. This can pose a problem to the health care supply chain, which relies in no small part on third party logistics contractors or couriers to make deliveries into disaster areas. Conversely, widespread injuries or population displacement can send scores of people to health and community facilities which may have inadequate supplies or space.

Increasing frequency of extreme weather events can cause them to occur with inauspicious timing, a phenomenon which typically proves very difficult for emergency management agencies and relief non-government organizations. In particularly active seasons, strained resources and funding can slow down the response efforts of government agencies. For instance, Harvey, Irma, and Maria all made landfall within three weeks of each other, causing dire shortages in funding and resources (43).

The need for additional monetary allocations skyrockets with compounding disasters, with relief personnel and supply often ending up spread very thinly. With a demonstrated increase in major disaster declarations in recent years, the possibility exists that certain areas – like Louisiana Gulf Coast, parts of California, and regions of tornado alley – may experience successive catastrophes, likely before they have fully recovered from previous ones *(42,43)*.

Supply chains and deployments of relief personnel and goods also present challenges, which was especially evident in post-Maria Puerto Rico. Responders were faced with the task of navigating legislation like the Jones Act, which mandates that only ships which are American-made, owned, and operated can move cargo between US ports *(44).* These efforts were further complicated by destroyed roads, making it so trucks could not mobilize to complete their deliveries. Loss of power also complicated the response logistics by creating inabilities to communicate and direct efforts for relief. Both were major problems which resulted in many instances of incomplete deliveries or supplies perishing at port, unable to be moved to their destination *(45).*

WEATHER THREATS WHICH CAN POSE RISKS TO HUMAN HEALTH

As briefly touched upon in the previous section, weather disasters can cause severe impacts to populations, infrastructure and the environment. These impacts often have direct and vast public health consequences which can be devastating. Many public health agencies provide resources to help track these consequences and make recommendations based on their occurrence, such as the US Centers for Disease Control and Prevention (CDC) Morbidity and Mortality Weekly Report. This type of reporting is crucial to understanding how various risks, such as weather threats, impact human health.

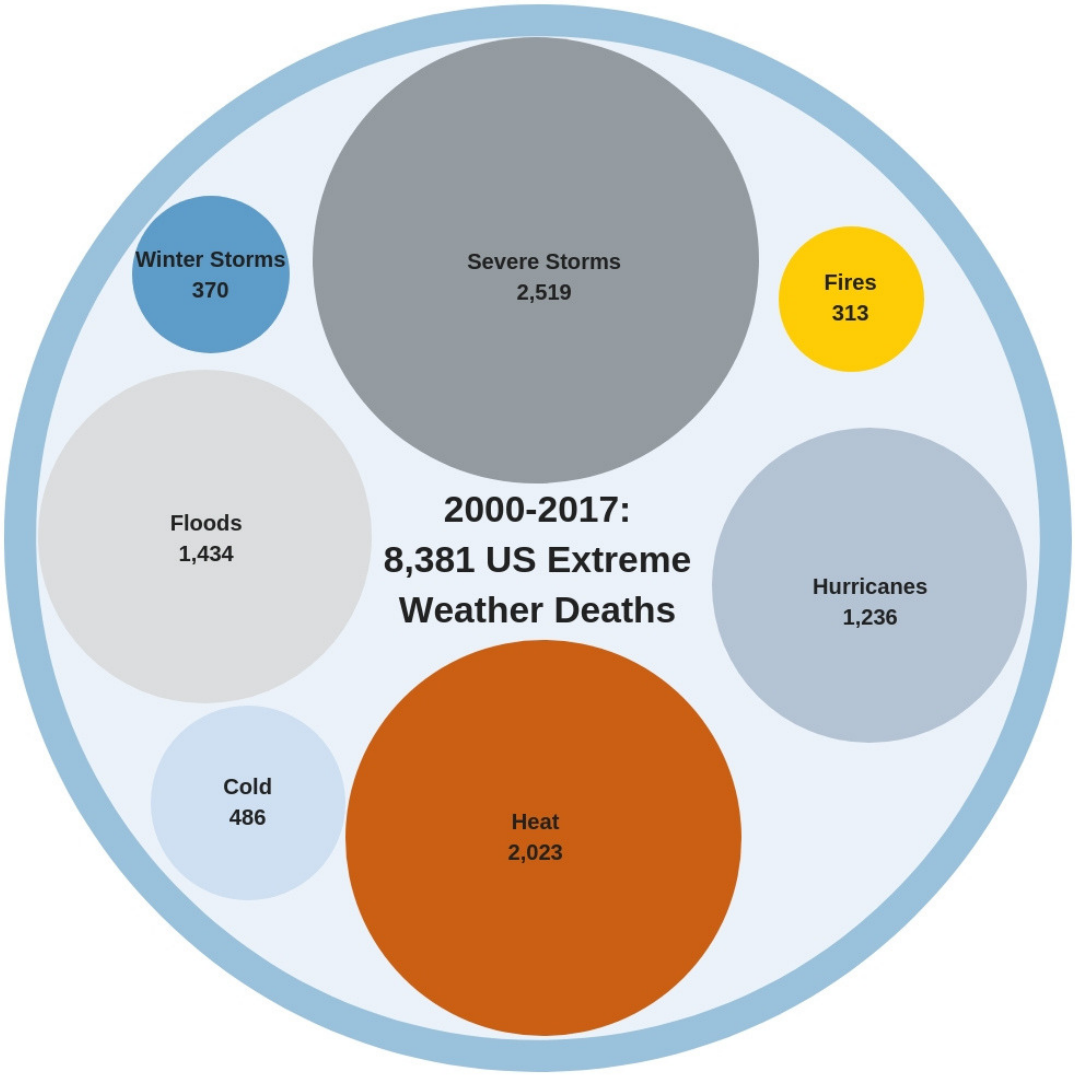

Figure 5. Causes of weather-related mortalities from 2000 - 2017 *(46)*.

Hurricanes and flooding

When hurricanes make landfall, they bring with them torrential rain, high winds, and storm surges. These secondary weather systems push sea water inland into coastal areas, often leaving standing water in their wake. For instance, Hurricane Harvey dumped upwards of 50 inches of rain in certain areas of Houston, destroying nearly 150,000 houses and affecting over 13 million people *(47).* This, combined with the high winds of a storm, can lead to widespread power outages.

A lack of power can be particularly devastating to health supply chains. When hospitals and clinics lose power, they lose the ability to properly store temperature-sensitive supplies including insulin, certain antibiotics, and vaccines.

Loss of power also brings a new array of challenges for pharmacies which use online tools for processing and verification of prescriptions. This holds true regarding communications with insurance companies for payment assistance. A widespread problem in Puerto Rico, the inability of pharmacies to process prescription information for patients seeking their medications caused many to go without their medicines or be forced to purchase the medication out of pocket.

Bacterial Infections Widespread Following Hurricane Harvey

Contamination of floodwater was well noted in the wake of Hurricane Harvey. Hospitals saw a spike in skin and gastrointestinal infections. Hurricanes leaves standing water, often inundating warm, tropical areas in their wake, creating ideal conditions for waterborne pathogens to thrive. About a month after the storm hit Texas, multiple deaths were attributed to bacterial septicemia and extremely high E. coli concentrations were recorded in water samples from Harris County, TX *(48)*.

Increased risk of infectious disease transmission also closely follows flooding events *(48)*.Infectious diseases are conclusively more prevalent in the wake of severe weather, due to factors like **standing water** and **overcrowding** *(49).*

- **Standing water** brings people in flooded areas into direct contact with many health threats from toxins to infectious agents. CDC lists diarrheal diseases, causative agents of skin infections, and industrial chemicals as top risks from floodwaters. Exposure to these contaminants in floodwater can cause a sharp immune response, eliciting flu-like symptoms and leading to an overall increase in the likelihoods of skin infections, gastroenteritis, and other, longer-term health effects *(50).* This was especially prevalent in the industrialized regions of Houston which had flooded following Harvey. Less than a month after the storm hit, the Environmental Protection Agency (EPA) had reported more than 40 chemical, energy, and other industrial sites in and around Houston had released contaminants as a result of the floods *(51).*

In the same regions, *E. coli*, a major indicator for the presence of fecal matter, was measured in floodwaters to be at concentrations 400% higher than normal levels *(52).* Water samples from flooded homes in the area fared equally poorly, containing elevated levels of toxic heavy metals such as lead and arsenic, in addition to polycyclic aromatic hydrocarbons – known carcinogens often found in proximity to fuel and energy processing facilities in Texas *(53,54).* Further, standing floodwaters, especially in the hot, humid Gulf Coast states, provide conditions ripe for exploding vector populations, which have been linked to increases in insect-borne disease outbreaks, among them Zika, West Nile fever, and yellow fever *(55,56).*

Extensive flooding and standing water in structures leads to the proliferation of molds, which can have long-term health impacts. Ranging from mild respiratory tract irritation to severe breathing troubles, the health effects of mold exposure can be extremely dangerous, especially in patients with pre-existing respiratory conditions *(57).* The long-term impacts of the floodwaters from the 2017 hurricane season have yet to be seen, however mold hazards have followed closely with most recent major flooding events and can have lingering impacts, most notably on residents of lower income housing projects *(58).* A 2010 study found that in the post-Katrina landscape of New Orleans, multitudes of relief workers and residents were exposed to extremely high levels of many different mold types *(59).* Similarly, a survey of residents from areas of New York reported mold growth in public housing more than four years after the landfall of Hurricane Sandy *(60).*

Risks from flooding, especially along the US coasts, is expected to increase drastically as sea levels rise. Many of the most densely populated cities on the Gulf Coast at or very close to sea level **(See Table 1)**. Sea level rise is projected to be more than half a meter by 2100 for the Gulf Coast region , a factor which could directly lead to far more flooding in those regions, eliciting health care complication *(61).*

Cities across the country can respond to this projected rise in sea level by taking several measures or implementing certain policies. Restricting new construction in flood-prone areas is one option for coastal cities. Additionally, upgrades to existing structures to include stricter building codes and flood defense capabilities such as floodwalls and levees *(62).*

Major Gulf Coast Cities' Vulnerability to Sea Level Rise

	Houston, TX	Miami, FL	Mobile, AL	New Orleans, LA
Average Elevation	**80'**	**6.5'**	**10'**	**0'**
Population	**2,303,000**	**454,000**	**193,000**	**392,000**
Average Time Between Hurricane Landfall (State)	**2.6 years**	**1.4 years**	**7 years**	**3.1 years**

Table 1. Elevation of four major US Gulf Coast cities and their vulnerability to hurricane strikes *(63).*

- **Overcrowding** also poses unique health risks following hurricanes or massive flooding. Often, evacuees or those who have sought shelter after losing access to their homes because of a storm end up finding refuge in community centers, tent cities, or other repurposed facilities. These shelters can quickly become unhygienic, and access to clean water may be limited. Under these conditions, certain infectious diseases can spread through the crowds of displaced people like wildfire. Depending on the immunization status of the population, less common diseases may spread, such as measles or meningitis *(64).*

  Patients with dependencies on electric medical equipment, oxygen tanks, and other devices face challenges and elevated risks in shelters. Those with weakened immune systems or otherwise greater susceptibility to infectious diseases must take extreme caution in these environments and pay close attention to any wounds which may become infected *(65).* Possibilities of limited fresh water and hot, stagnant conditions which can be rampant in shelters put the chronically ill and other ill populations at elevated risks.

Extreme heat and drought

Heat waves, or extended periods of extreme heat typically accompanied by high humidity, are often direct consequences of increasing global temperatures *(66).* They can be very dangerous, often causing death or severe illness through dehydration, heat stroke, or heat exhaustion. Heat-induced ailments occur when the body is no longer able to regulate its internal temperature. Specifically, during heat stroke, the body cannot adequately cool itself by sweating, and the internal temperature rises drastically. This can lead to to cognitive deficits and, in many cases, death *(67).* Since 1979, more than 9,000 people in the US have died from heat-related causes *(68).* Each year, heat is responsible for more US deaths than flooding, hurricanes, severe storms, and hurricanes combined *(69).* Risk factors for heat-related illness include:

- Age, particularly the young and the elderly (*70*).
- Taking prescription medications, especially for aggravated heat conditions *(71)*.
- Low-income populations with limited access to air conditioning and water *(72)*.

Heat-related conditions disproportionately impact lower-income individuals, especially non-Hispanic Black persons in highly populated urban areas *(73).* The heat island effect, a phenomenon where urban areas experience temperatures five or more degrees Fahrenheit greater than surrounding areas , can make living in big cities during heat waves especially dangerous for those with preexisting conditions *(74).*

Persistent high heat days contribute to an influx of patients seeking emergency medical care, crowding and straining hospitals and health clinics *(75).* The heat island effect has been worsened in recent years, and cities across the US including St. Louis, Philadelphia, Chicago, and Cincinnati have seen increases in heat-related mortality *(76).*

Severe storms and tornadoes

Severe thunderstorms are extremely common in the US, especially in the spring and summer. Bringing with them the likelihood of strong winds, heavy rain, large hail, lightning strikes, and tornadoes, severe thunderstorms represent a uniquely diverse threat to public health. While any of these can be life-threatening – especially flooding and lightning – tornadoes are by far the most dangerous to human life and property.

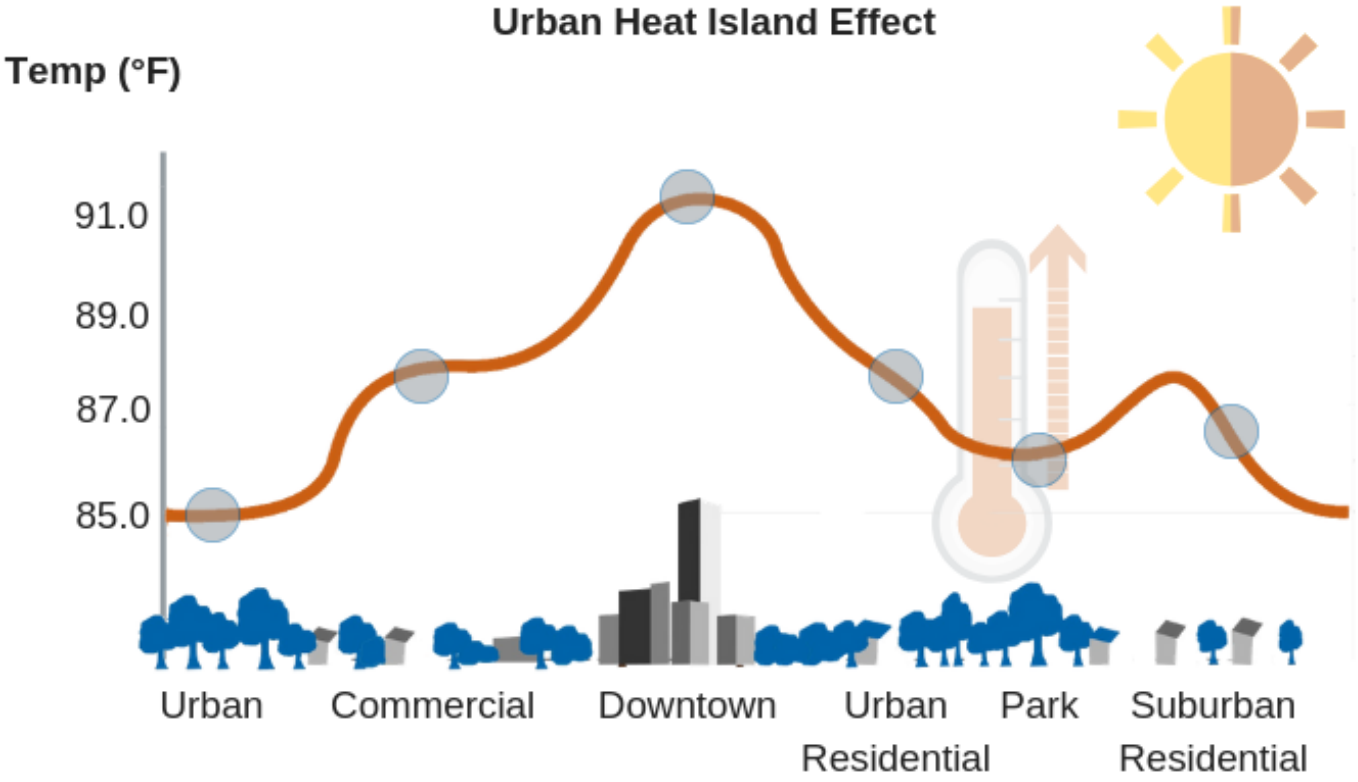

Figure 6. Visualization of the changing temperature profile of various community types due to the heat island effect *(77).*

Severe thunderstorms often occur as parts of larger systems known as outbreaks which spawn multiple tornadoes and other thunderstorm threats over a period of days. The average toll from severe thunderstorm activity in the US includes 1,500 injuries and 100 deaths, however individual outbreaks can inflict much greater damage at higher costs *(78).* The 2011 Super Outbreak, for example, was a 3 day-long event featuring almost 400 tornadoes across the southeastern US in late April. This was the single deadliest outbreak in American history, where 324 people lost their lives and more than 3,000 were injured *(79).* Weeks after the outbreak, thousands across Alabama, Georgia, and Mississippi had to face the oppressive heat and humidity of the Dixie spring without electricity, clean water, and in some cases, shelter (80).

To further complicate the crisis, some areas were left with significant damage to their communications infrastructure, drastically slowing FEMA and Red Cross efforts to provide relief and supplies to the victims.

While destructive and deadly outbreaks like the one in 2011 are not necessarily common, neither are they exceptionally rare. Recently, they have been occurring with greater frequency. A 2016 study showed that since 1954, the average number of tornadoes spawned by an outbreak has increased by nearly 40% *(81).* Public health stakeholders in storm-prone areas must become more vigilant in developing preparedness and response protocols for the ever-increasing frequency and severity of tornadoes.

Winter weather

Strong winter storms are another set of extreme weather events which can have marked impact on public health, for which healthcare and public health must also devote resources for mitigation efforts. Heavy snowpack can block access to many residences, cutting off individuals from accessing areas outside of their immediate vicinity or being reached by caregivers. High winds and blowing snow create hazardous conditions which make driving difficult, often causing delays in deliveries and resupply of critical medical supplies.

Blizzards and Nor'easters are among the most dangerous types of storms, bringing with them high winds, heavy snowfall, extreme cold temperatures, and the risk for significant icing. Conditions associated with these storms typically include high winds combined with heavy snowfall or ice. Often accumulating on power lines, they carry a high risk of knocking power out and causing dangerous losses of heat. The worst of these winter storms can cost upwards of $3 billion, disrupt travel, industry, and commerce for up to a week, and pose threats to human life *(82).*

Developing Resilient Health Systems

Healthcare systems and public health departments have been taking important actions to prepare for and mitigate against the threats extreme weather events pose. With resilience to such events a moving target, and with many health systems and public health departments confronting this new normal with limited or diminishing resources, Healthcare Ready believes focusing energy and investment in three key areas is vital as the field continues to adapt to the current and future threat environment.

BUILDING AND INVESTING IN RESILIENT INFRASTRUCTURE

As scores of studies and real-world experience demonstrate, bolstering resilience in the infrastructure of health systems is an essential step for reducing the damages from storms and other weather-related disasters. Informed by hard lessons learned from Hurricanes Katrina and Sandy, many hospitals – particularly in high-volume or high-risk areas – have added certain waterproof door systems which function to seal off on-site critical supplies stores and power generating rooms *(83)*.

Building power and communications redundancies into systems, to the greatest extent possible, is another important means of increasing resilience. Hurricane Maria served as a stark reminder that sustained outages can occur. Alternative communications systems and platforms, such as satellite phones, cross-platform smart phone apps, and signal enhancers and repeaters are a few examples of technologies that can strengthen communications plans.

New Orleans Builds a Hurricane-Proof Veterans Affairs Hospital

Implementing higher building code standards for hospitals is a way to ensure continuity of healthcare during and after a storm. In New Orleans, a brand new "hurricane-proof" hospital was constructed after Katrina destroyed most of the previous healthcare facilities. Capable of independent operation for almost a week, the hospital houses its water, power, and supplies centers, elevated at least 20 feet above flood level. It also stores over 300,000 gallons of fuel, houses food supplies, and has roof-top rainwater collection tanks. New codes are likely to reduce the damages incurred by future storms, but they generally don't apply to older structures, leaving them susceptible to weather and creating risks for those seeking care therein.

Source: The Wall Street Journal (84).

Inclusive Planning with Emergency Management and Health Officials

Developing strong and resilient health systems goes far beyond the traditionally-viewed health stakeholders of hospitals, pharmacies, and health providers. As previously discussed, the needs of different communities at all levels vary. Accordingly, disaster preparedness and response protocols must be developed using community-level input.

Effective emergency health management requires partnerships between all health stakeholders within a community, such as government and government agencies, private companies and non-government organizations, and physicians and clinics. The creation and promotion of healthcare coalitions (HCC) has been a very important development in this regard. Serving as the nexus of multi-agency coordination, HCCs have begun to play much more pivotal roles in their communities, helping to establish preparedness and response capabilities of health systems. Usually comprised of, at minimum, a healthcare facility, emergency medical service providers, emergency management organizations, and local public health departments, HCCs are collaborative and aim to ensure each stakeholder is represented and equally prepared for emergencies.

These healthcare coalitions working in constant communication during a disaster serve to facilitate effective incident response through the streamlining of communications, supplies, and by working with lawmakers and authorities during times of crisis or medical surge *(86).* By representing so many different stakeholders, healthcare coalitions have unique leverage and the ability to lobby on behalf of and secure funding for the distinct needs of a community's entire health system.

These coalitions typically have outstanding grassroots support from the community and are a trusted avenue for patient advocacy groups to make the voices of the patients they represent heard. The need for community input and trust is bursting onto the forefront of resilience planning, and many cities have launched initiatives to truly provide their citizens a platform to participate in augmenting the city's ability to handle an emergency event.

Baltimore Resiliency Hubs

The Baltimore Office of Sustainability piloted the establishment of four resiliency hubs around the city in churches and community centers. The hubs will bring the community together to help prepare, respond to, and withstand emergencies and disaster situations.

During a crisis, residents of Baltimore can gather here to get critical supplies and shelter. On a day to day basis, these centers will serve to provide education and resources on health, resilience, and overall wellness.

Source: Baltimore Office of Sustainability (87)

Private-Public Relationships and Partnerships Play a Role in Resilience

The ability for the private sector, which owns or operates 92% of all healthcare, to work collaboratively with government agencies and the member of communities is critical in establishing resilience *(88).* Partnerships or organizations which link the two spheres play an essential role in information sharing and protecting healthcare continuity. This is especially true during emergencies, where public emergency management and health services are relied on heavily by the affected populations, as efficiently working with the private sector in those strenuous times can keep the flow of health supplies and services moving.

Private-public partnerships and non-profits also play a crucial role in bringing together organizations from both sectors to bridge gaps. Often, individual sectors or organizations do not have the time or resources to self-organize or otherwise seek public-private partnerships, relying heavily on a convener like our organization. By coordinating between the two and facilitating the share of information, organizations like ours can share best practices and connect resources to demonstrated need.

CONCLUSION

As the effects of climate change continue to have ripple effects on weather patterns, extreme weather is likely to have greater, more severe impacts on human health. Dangerous weather can come in all types, from extreme temperatures to wildfires to strong storm systems like hurricanes, blizzards, severe thunderstorms, and torrential floods. Certain populations are much more vulnerable to the effects of these events, posing a significant public health risk.

To mitigate the health risk posed by ever-strengthening severe weather, communities must establish and leverage partnerships which can link the private sector, which owns a vast majority of health services, and the public sector, which is heavily relied upon to provide care during an emergency, together. The unique position of Healthcare Ready and the relationships our organization has positions us well to do so.

Similarly, healthcare coalitions may be used to further develop working collaborative efforts and serve to develop public health resilience to the litany of threats posed by unpredictable extreme weather.

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