Implications of Extreme Weather Events

ABSTRACT

The United States and the rest of the world is contending with increasingly common extreme weather events that threaten U.S. national security. These extreme weather events have significant primary and secondary effects on the full range of critical infrastructure sectors (and their supply chains), many of which enable key U.S. Government functions or support American society. The report examines public-private practices and methodologies to address the current and evolving threats to national security from extreme weather events. This analysis focuses on best practices and frameworks to be developed or updated by 2035 to address extreme weather threats out to 2050. We begin this analysis with an overview of the threat landscape to identify the types of extreme weather threatening the United States and the world and the expected trends across each event type in the coming decades. The report assesses the national security implications of these weather events and how extreme weather events intensify existing threats or degrade the ability of the U.S. Government and the private sector from performing critical functions. We highlight the importance of public-private cooperation to address the threat of extreme weather events through two case studies included in this report. The first case study examines the impacts of Hurricane Maria on the pharmaceutical industry's supply chains and the steps pharmaceutical companies have taken to build resilience. The second case study analyzes steps taken by the semiconductor industry in Taiwan to address a drought in 2021 which challenged manufacturing and threatened the global supply of microchips. The report provides mitigation options tied to specific extreme weather events and public-private best practices observed during the production of the case studies and interviews with government and industry leaders. The report aims to give public and private sector stakeholders actionable steps they can implement in their organizations to build resilience and mitigate the impact of extreme weather events on national security.

To ensure the widest use of this research, the ESRI platform will hold interactive datasets convening current weather research, modeled forecasts in shifts for each extreme weather event trigger, thresholds for potential impact, and the case studies to focus data pertinent to each region, sector, and national security implication key concept of their concern. The platform allows for display maps which pull the most up to date graphics, enabling this product to self-update and remain timely as new models and studies debut and can produce consolidated summary pages.

- The user will be able to access the site, drill down to their region, infrastructure, or weather event of note and their current impacts and;
- Use existing tools from subject matter experts to identify the worsening trends in each major weather event type to isolate which concerns to address immediately and;
- Identify best practices most applicable to their focus and possible sourcing of funding to offset implementation costs.

The ESRI product will be maintained by DHS and updated as more tools, resources, and funding opportunities become available, making this product a living document and a collaborative effort.

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EXECUTIVE SUMMARY

The coming decades of the 21st century will pose a variety of threats to the national security of the United States. States like China, Russia, and Iran are working to challenge U.S. presence in key regions or sow chaos across the world. Non-state groups, including domestic violent extremists, continue to promote hateful ideologies and launch attacks across the world against civilian populations. While these threats all pose a challenge, the trends observed with extreme weather events will hit harder, more regularly, and closer to home for the United States than any external threat. Climate change is hastening the pace of extreme weather felt across the United States with stronger storms, more intense droughts, and rising seas primed to cause significant human, physical, and financial damages between now and 2050. Beyond the immediate loss of life and damage to property, these extreme weather events have real implications for the national security of the United States. Climate change and the extreme weather events it can cause are intensifying conflicts, spurring mass migrations, destroying critical infrastructure, and undercutting the ability of the U.S. military to maintain and project power. All of these cascading impacts of extreme weather events are real and are being felt across the country. Not all of these impacts are obvious. For example, Hurricane Maria's devastation of Puerto Rico caused significant disruptions to the pharmaceutical supply chain in the United States with impacts felt across the healthcare system. Similarly, a widespread drought in Taiwan almost crippled the country's ability to produce advanced computer chips essential to a range of high-end military and civilian technologies. In both cases, extreme weather events set off a chain reaction with measurable impacts felt through the economy, international supply chains, and the ability of the U.S. Government to safeguard the country. The U.S. Government and the private sector, even working together, cannot fully eliminate the risk of climate change induced extreme weather events. However, there are mitigation steps that the public and private sector can take when building and designing infrastructure to save lives and promote resilient industries. There are also numerous opportunities for the private sector to work with the U.S. Government to promote information sharing, conduct risk assessments, and pursue effective resilience measures. Extreme weather events will test the nation in the coming decades, but with smart policy and targeted action, the United States can work to stave off the worst impacts of increasingly damaging climatic and weather trends.

THREAT LANDSCAPE

Extreme Heat

In the United States, annual temperatures are warmer than the 20th century average regardless of geographical location and recent years have set numerous records, including over 100,000 daily temperature records tied or broken. Since temperature records began in 1880, the ten warmest years have all occurred since 2010, with 2014 – 2022 as the nine warmest years on record. These record elevated temperatures increase mortality and morbidity in North America.[i]

In the 1980s, concurrent heat waves only occurred for 20-30 days each summer. Global warming has driven a sixfold increase in the frequency of simultaneous heat waves over the last 40 years. The study also found that concurrent heat waves covered about 46% more space and reached maximum intensities that were 17% higher than 40 years ago. Extreme Heat can vary based off the region for impacts but is generally understood to be temperatures over 95 degrees with high humidity for at least three days.[ii] Typical humidity levels and baseline temperatures are variable across the United States due to the expansive topography and climate zones within the country. High temperatures in Maine have a lower threshold than Texas whereas humidity levels typical in Florida would have more significant impacts in Arizona. Using temperature and humidity levels, forecasters can identify thresholds for operating both for people and for infrastructure with two main indicators: the heat index and wet bulb condition.

The heat index considers temperature and relative humidity to determine what the temperature feels like for the body. With a high humidity percentage (>90%), temperatures below 90°F can feel like temperatures above 103°F - the minimum apparent temperature for extreme heat consequences.[iii] The heat index is also specifically calculated for shady areas. According to NOAA, when heat and humidity are too high for sweat to evaporate from the skin - the body's natural cooling mechanism – wet bulb conditions begin.[iv] If the temperature and humidity both exceed 95 degrees, wet bulb conditions can be fatal for even physically fit individuals.[v]

Heat waves turning into heat domes have become an annual occurrence over the past decade, with both the frequency of high heat days and the peak temperature on those days increasing year over year across the United States. A heat wave is a period of unusually hot weather lasting two or more days.[vi] A heat dome occurs when the atmosphere traps hot ocean air like a lid or cap and typically covers a larger geographical area than a heat wave for a longer period.

As the atmosphere continues to warm at an uneven rate, meaning parts of the globe will experience greater heat than others during certain periods, more evapotranspiration can occur at the surface. Evapotranspiration is the sum of all processes by which water moves from the land surface to the atmosphere via evaporation and transpiration.[vii] Water vapor is a greenhouse gas responsible for rainfall events, moisture content throughout the air, and even trapping in heat.[viii] As evapotranspiration increases from longer periods of direct sunlight (solar radiation), water vapor increases, further amplifying the water vapor presence and trapping in even more heat creating a continuous cycle of warming to compound with carbon and methane releases coupling with pollution output to produce unsustainable rates of heat over the coming decades.

Populations across the United States (the heat is no longer regional only) are struggling throughout the summer months of 2023 as heat waves bring record breaking highs and consecutive days of triple-digit temperatures. These heat waves will become increasingly common in the coming decades and pose a direct threat to human life while straining critical infrastructure. A study conducted by the First Street Foundation found the number of U.S. citizens exposed to regular temperatures exceeding 125°F will increase from 8 million to 107 million by 2053 with an 'extreme heat belt' accounting for heat and humidity stretching from Texas to Illinois. The significant rise in exposure to extreme heat poses an amplified risk to certain populations based on data from the Environmental Protection Agency (EPA) and the U.S. Centers for Disease Control and Prevention (CDC). Urban populations, young children, older adults, and those with some preexisting medical conditions or on particular medications are particularly vulnerable to life threatening conditions caused by extreme heat.

Extreme heat kills more Americans on average per year than any other extreme weather event, a trend that is likely to worsen given expected extreme heat trends by 2050. The impact is also felt on the nation's critical infrastructure sectors – the Cybersecurity and Infrastructure Security Agency (CISA) notes that extreme heat can lead to the degradation of numerous types of structures, cause damage to transportation modes, increase power needs for cooling which can overload existing power infrastructure, and can result in expansive crop decay and livestock deaths amid other impacts.

Some materials, such as concrete and cast iron, are particularly prone to cracking in extreme heat to relieve stress, compromising building infrastructures. Electrical infrastructure can also be compromised in extreme heat, as both power lines and transformers become less efficient when overheated. Increased air conditioning demand during heat waves can further stress the system. The combination of less efficient power delivery and excessive demand increases the burden on community utilities and can lead to rolling blackouts and power outages.

For individuals in sealed buildings, interior spaces can become uninhabitable, and datacenters, even with emergency power, may need to reduce operations or shut down completely to prevent electronic equipment from overheating and becoming damaged. Extreme heat also impacts agricultural productivity, limiting working conditions and decreasing crop yields

Graphic possible for use – NOAA climatology on heat or a forecasted heat expansion from IPCC report (the next NCA comes out this fall making it too late)

Extreme Cold

During a time of widespread warming events, sudden freeze events can seem like a violation of trends when realistically these events are more likely to be intense and fluctuate outside of seasonal norms given the uneven amplified warming trends globally. The jet stream has three main components in the northern hemisphere, the Arctic Jet, the Polar Front Jet, and the Sub-Tropical Jet. Extreme swings in temperature are indications of changes in stability of the atmosphere's upper levels, resulting in more intense storm events impacting multiple regions simultaneously. The jet streams are the main movement belts for atmospheric pressure centers (lows and highs) across the globe, moving them either towards the West or East, depending on the jet stream, with variation in longitude of pressure centers which can enable surges of air masses into regions less prepared for them. Due to this shift, typical winter storms can align with arctic low-pressure centers wrap into one-another, pushing arctic air further south than normal, into warmer regions not built to withstand the intensity or persisting sub-freezing events. These events are more commonly known as Polar Vortex Events and occur when the Arctic Jet Stream becomes unstable, which will occur more often in an unevenly warming climate, making them more difficult to forecast and likely more damaging.[ix]

Extreme cold occurs when temperatures are lower than historical averages for the region to the point that it creates a dangerous environment; a cold wave is when temperatures rapidly fall within a 24-hour period and extreme low temperatures persist for an extended period. In the northern United States, extreme cold can reflect temperatures well into the negatives; however, in southern states, temperatures below freezing can cause severe damage to crops ￼ Additionally, wind chill accounts for the temperature and expected wind speeds causing temperatures to feel even colder for the body. This can cause sweat to evaporate from the skin at a greater rate and further cool down the body resulting in a greater risk of bodily harm. Similar to the worsening trends with heat indices during extreme heat, when wind chill occurs during an extreme cold event the effects to people, livestock, and infrastructure are all amplified.

Extreme cold often coincides with winter events, such as blizzards and ice storms. Blizzards consist of falling and/or blowing snow alongside sustained wind or frequent gusts of at least 35 miles an hour for at least 3 hours; visibility is also often reduced to less than a quarter of a mile. Ice storms occur when damaging accumulations of ice are expected from freezing rain, which can stress and break tree limbs and power lines from the significant addition of weight.

Despite the overall warming of winter temperatures due to climate change, mortality rates attributed to cold temperatures persist in North America. Hazards caused by winter storms include hard-freezes, icing, freezing rain, heavy snow, ice storms, freezing fog, and lake effect snow, all of which are intensified by shifts in the polar vortex stability, another effect of climate change.

Climate models indicate global cold extremes are overall expected to decrease over the next 75 years; however, mortality rates are unlikely to decrease for the current generations as intense winter storm events and regional freezes remain a threat. Higher regional variability of climate models suggests cold waves will have a greater impact with climate change, especially in regions where there is less preparation and capacity to adapt to extreme cold. A strong, polar stable vortex maintains the arctic air near both poles, while a disrupted and weak vortex causes freezing air to extend into further south latitudes while allowing warm air to push further north. Current model simulations have yet to come to a conclusive decision on the extent global warming will impact the stability of the polar vortex.[x]

A recent study highlighted that there has been a 21% decline in the April 1st snowpack water storage in the Western U.S. since the 1950s – which is equivalent to Lake Mead's storage capacity.[xi] The peak annual snowpack in the Cascades could decrease by 25% in the next 30-60 years according to the study. There have been decreases in peak snowpack volume as well as earlier occurrences of the timing of peak snowpack, with the peak occurring approximately 8 days earlier in the year for every 1 degree Celsius (1.8 degrees Fahrenheit) of warming. California could experience episodic low-to-no snow beginning in the late 2040s and low-to-no snow in the 2060s according to some climate projections. This could cause cascading snow loss into Central US. For other parts of the Western U.S. persistent low-to-no snow emerges in the 2070s which extends across the Rocky Mountains.[xii]

Extreme cold is a hazard to communities and burdens electrical systems as the demand for heat increases. Frozen electrical equipment (e.g., transformers, windmills, solar panels, and fuel pipelines) can limit the ability of electrical systems to meet energy demands, while ice can weigh down powerlines and tree branches to the point of breaking, causing additional disruptions to power delivery and in-person repairs during hazardous conditions. Sites in warmer climates are likely unprepared for extreme cold and could see damages to supporting infrastructure like utilities using pipelines, such as water, oil, or gas, which may not be sufficiently insulated could crack due to freezing conditions. These conditions can become exacerbated due to winter storms, which can last for several days, and disproportionately affect vulnerable populations with limited access to resources. The additional stress on electrical systems may result in blackouts or power outages. With limited or no access to heating systems, households may turn to space heaters, wood fireplaces, or inappropriate heat sources such as gas stoves, outside grills, and ovens for warmth, but these alternative methods can cause hazardous air quality inside or result in house fires.[xiii] [xiv]

Even during the warmest months historically, polar air has persisted with arctic air at both poles and likely will remain through the next few decades despite overall warming trends. The shifts in types of precipitation indicates larger areas where slush, freezing rain, and ice storms could develop which historically would see more even distributions of snowfall developing a robust snowpack for slow melting into rivers, reservoirs, and aquifer systems in the spring. The changes in winter weather events like blizzards in warm climate areas, ice storms becoming more expansive, and shifts in snowfall events toward freezing rain, and eventually solely rain, make planning for surface water and infrastructure operations during these months more difficult. This harsher climate is less understood by the scientific community for what future winter seasons could look like, but the coming decades will present greater threats to water security regardless as the shift in beginning and end of winter have cascading impacts to the agricultural sector, waterways, sea ice, permafrost melt rates, mountain precipitation runoff rates, and regional subsidence.

Larger Wildfires

A wildfire is an uncontrolled fire in the wildland vegetation, often in rural areas. Wildfires can burn in forests, grasslands, savannas, and other ecosystems, and have been doing so for hundreds of millions of years. Megafires are defined by the U.S. Interagency Fire Center as a wildfire which burns more than 100,000 acres of land.[xv] Other wildfire experts expand the definition of a megafire beyond "acres burned" to cover wildfires that have an unusually large impact on people and the environment. Wildfires are not limited to a particular continent or environment, and certain conditions can enable these fires to burn for months or years if conditions are right. Certain events, like coal fires can travel along coal veins underground as soft coal's ignition threshold is very low, and the fire can burn for decades before burning a vein near the surface and igniting the organic material in the area. Such events are rare but occur on every continent. The most well-known wildfires are typically caused by lightning or a by a human such as with campfires or vehicles, or in some cases through preventative measures like controlled burns which can become uncontrollable in worsening weather events. Topography plays a big part too: flames burn uphill faster than they burn downhill. Wildfires that burn near communities can become dangerous and even deadly if they grow out of control.

According to NASA, 61% of western wildfires have occurred since 2000 with a steady increase in the number of wildfires over the last 60 years.[xvi] As the globe continues to warm at uneven rates, surface moisture will face greater variances in evapotranspiration resulting in regions of the United States experiencing persisting drought conditions over multiple years which can cause widespread vegetation decay and generational shifts in the ecology of a region. These shifts in saturation of soils and plants result in threats of wildfires burning at greater intensity as the dried vegetation acts as combustible tinder-like material. High temperatures, low relative humidity, high wind speed, and low precipitation can all increase dryness and make vegetation easier to burn. A study from the University of Colorado states wildfires have become larger, more frequent, and more widespread since the year 2000. Some fires are even occurring in areas that have already experienced fires, known as burn-on-burn effects. About 3% —almost a third of the burned land—has seen repeated fire activity.[xvii] While many in the United States hear wildfire and think of the West, wildfires occur in every state to include topical locations. Trends are indicating even Hawaii and Alaska are burning at greater rates the last decade when compared to decades past. Satellite imagery and state/federal fire history records from 28,000 fires in 1984-2018 showed more fires occurred in the past 13 years than the previous 20 years. On the East and West coasts, fire frequency doubled. In the Great Plains, fire frequency quadrupled. There were more fires across all regions of the contiguous U.S. from 2005 to 2018 when compared to the previous two decades.[xviii]

Once a wildfire burns through an area, a general ecology shift occurs where the robust plants have either been damaged or destroyed and the undergrowth burned out. This exposes more soil and surviving trees to direct solar radiation and wind, drying them out more rapidly than normal and fueling a new area of decay for wildfire threats over time. Additionally, areas post-burn, also known as burn scars, will see greater runoff rates during rainfall events as soils compact from heat and drought, resulting in less water absorbed during storms while fewer trees are present to act as force blocking for runoff. This results in faster moving waters through an area, typically pulling topsoil away without tree roots to hold surface materials in place. This can result in greater mudslides or landslides and sediment deposit into rivers and reservoirs which reduces both the water quality of the area and the capacity of water storage. A study from the University of Montana highlights burn-scar impacts to tree regrowth across various regions, indicating new tree seedlings are unable to survive in hotter climates where parent trees remain. The study indicated that if large areas of the forested parts of the Rocky Mountains burned, only 50% would recover.[xix]

Analysis of coincident 1000-hour fuel moistures indicated that as fuels dried out, satellites detected increasingly larger and more intense wildfires with higher probabilities of nighttime burns. Research suggests that global warming is predicted to increase the number of very large fires (more than 50,000 acres) in the Western U.S. by the middle of the century (2041-2070).[xx]

Burned vegetation and charred soil form a water repellent layer, or hydrophobic layer, which can reduce water absorption combined with compacted soils from extended periods of drought which also inhibits water absorption regionally. These major soil changes cause short rainfall events to be less beneficial for long term vegetation to take sustain. As fires burn wider areas and into higher elevations topography shifts from tree-creep, soil composition changes, soot deposits, debris flows, burn scars, vegetation/foliage decay, early blooms, flooding post-burn, less wildfire activity, and increased pollution from wildfire smoke, the cycle of heightened wildfire activity will worsen each year. Damaged soil from heat transfer result in less fire-resistant plant retention and more scraggly brush growing back between fire weather active periods.

Large wildfires in the right atmospheric conditions can create Pyro-cumulus clouds. These clouds reduce flight ability in the area and surface visibility during development and can amplify fire growth as they develop severe storm cell traits by causing erratic surface wind gusts, lightning ignitions, downbursts, and even tornadic activity. Smoke from fires can feed the growth of toxic algal blooms, diminish the milk production in livestock, decade energy transmission, reduce air quality, and cause harmful lasting impacts to the human body. While not all wildfires are “bad” for the environment, the presence of infrastructure and people further into wildland areas susceptible to wildfires has led to a shift in response to extinguish most fires immediately as they occur, leading to greater compilation of undergrowth and scraggly brush or weaker trees which also contributes heavily to the worsening situation at hand.

The National Oceanic and Atmospheric Administration (NOAA) reports wildfires caused $81.6 billion in damage in from 2017 to 2021, a nearly 10-fold increase from 2012 to 2016, when damages totaled $8.6 billion. The U.S. Department of Agriculture states forest fires often reach or exceed temperatures of 2,000°

Fahrenheit—equivalent to one-fifth the temperature of the surface of the sun. This intensity of heat can melt almost any building material and either damage or destroy key sites if surrounding temperatures get too hot, regardless of if the fire touches the facility.[xxi]

A recent report from the United Nations Environmental Program estimates the world will see the rate of wildfires increase by 14% by 2030 and 30% by 2050 spurred by climate change.[xxii] A combination of factors are lengthening wildfire season in the United States including climate change induced high temperatures and droughts which lessen water availability in high-risk regions and changing land use.[xxiii] Wildfires will continue to get worse in the coming decades because the wildfires themselves create a feedback loop which increases the likelihood and intensity of future wildfires. According to the World Resources Institute, drier landscapes raise the risks of wildfires which can spread more widely and frequently given the dry conditions. These wildfires in turn lead to additional carbon emissions which intensify the climate change conditions creating the conditions for future wildfires.[xxiv] Wildfires can impact a broad range of critical infrastructure sectors and will pose a higher threat in the coming decades given the longer fire season and more intense outbreaks. Fighting wildfires is resource intensive and can pull firefighting, law enforcement, healthcare, and military assets away from other duties to address the wildfires and associated evacuations. In addition, the fires themselves pose threats to physical infrastructure of companies operating in the telecommunications, electric utility, and transportation sectors which can have cascading impacts throughout the U.S. economy.[xxv]

Prolonged Drought

There are two main drought events which impact a region, the overarching drought which is a period of abnormally dry weather sufficiently prolonged for the lack of water to cause serious hydrologic imbalance in the affected area, and a flash drought which is the rapid onset or intensification of drought. Flash droughts occurs when lower-than-normal rates of precipitation are accompanied by abnormally high temperatures, winds, and radiation and can be considered to have sudden onsets as predicators of heightened wildfire growth in the following months.

In a negative feedback loop, wildfire damage can amplify the drought impacts at the surface by removing trees and exposing soils to direct sunlight due to a lack of shade, stronger winds due to a lack of blocking which could cause additional drying and move loose, dried soil causing an increase in larger dust storms. In the last 100 years, there have been at least three major U.S. droughts. The 1930s Dust Bowl drought and the 1950s drought, each lasted 5-7 seven years and covered large areas of the country with significant impacts.[xxvi] The current multi-year drought across the West is the most extensive and intense drought in the 22-year history of the U.S. Drought Monitor with conditions rapidly deteriorating since 2020.[xxvii]

There are four main types of droughts: Meteorological, agricultural, socioeconomic, and hydrologic. Meteorological Drought is based on the degree of dryness or rainfall deficit and the length of the dry period. Hydrological Drought is based on the impact of rainfall deficits on the water supply such as stream flow, reservoir and lake levels, and ground water table decline. Agricultural Drought refers to the impacts on agriculture by factors such as rainfall deficits, soil water deficits, reduced ground water, or reservoir levels needed for irrigation. Socioeconomic Drought considers the impact of drought conditions (meteorological, agricultural, or hydrological drought) on supply and demand of some economic goods such as fruits, vegetables, grains, and meat. Socioeconomic drought occurs when the demand for an economic good exceeds supply due to a weather-related deficit in water supply.[xxviii]

There are also differences in longevity of the drought events which determines the severity of impact across a region. If the pattern and precipitation deficits last for more than six months, it is typically considered long-term drought. It is possible to have short-term changes that result in wet spells during a drought and for wet conditions to be interrupted by weather patterns that result in short-term drought.[xxix]

Drought can have a number of cascading impacts besides priming an area for wildfire activity. Drying of the soils can result in damaged crops, lower and warmer river systems which can impact supply chain movements, and even soil stability through subsidence and earthquakes. The primary cause of subsidence in the nation is due to groundwater overpulling from aquifer systems, in which typically during droughts when surface water runs low, residents turn towards ground water. Groundwater acts as an invisible savings account of water storage due to the semi-porous nature of soils and through the use of wells people can pull the water from the earth to use at the surface. This comes with clear implications that eventually the soils could dry out and crumble from the weight of the infrastructure on top, resulting in a collapsed aquifer and significant infrastructure damage.

Seismic activity is also reportedly impacted by drought events. The number of earthquakes in the Central U.S. has increased dramatically over the past decade. Between the years 1973–2008, there was an average of 25 earthquakes of magnitude three and larger in the Central and Eastern U.S. Since 2009, at least 58 earthquakes of this size have occurred each year, and at least 100 earthquakes of this size every year since 2013. The rate peaked in 2015 with 1010 M3+ earthquakes. In 2019, 130 M3+ earthquakes occurred in the same region. The gravity recovery and Climate experiment (GRACE measurements) reveals that major earthquakes (Mw 5 and above) always occur in the dry stage, indicating drought and associated groundwater extraction is an important trigger for major earthquakes. Earthquakes result from strain build-up and weakening from within faults. The loss of an estimated 63 trillion gallons of water in the Western U.S., most of it groundwater, was reported in a study done by researchers at the Scripps Institution of Oceanography. The loss of the water has caused the ground to rise more than a half-inch in California's mountains.[xxx] [xxxi]

Historic droughts caused significant damage to local ecosystems and critical infrastructure with the National Oceanic and Atmospheric Administration identifying 10 droughts between 2010 and 2021 which each caused over $1 billion in damages and from 1980-2022, there were 30 drought events totaling $309.4 billion dollars according to National Centers for Environmental Information.[xxxii] Climate change will drive additional periods of prolonged drought in the coming decades, particularly in the U.S. Southwest, as warmer temperatures hasten soil evaporation and rates of precipitation drop in regions supplying water to drier climates.[xxxiii] Prolonged droughts also have damaging impacts across critical infrastructure sectors. For example, reduced access to water from rivers and lakes can hamper energy production by taking hydroelectric plants offline or limiting the availability of water for cooling at certain power plants.[xxxiv] Decreased rainfall can result in draft and tow restrictions as water levels in the river system become too low to safely operate. About 60% of all U.S. grain exports move down the Mississippi River to ports in Louisiana, while fertilizer, metals, crude oil and other products move upriver.[xxxv]

Sea Level Rise

Sea Level is the average base level for coastal areas to measure elevation against the shoreline. Sea level is measured both by tidal gauges and satellites and can be reported as a global average or as local rates. Changes in mean global sea level, resulting from the transfer of fresh water from land to oceans (from land-based ice sheets and mountain glaciers) and from the thermal expansion of ocean water due to higher global temperatures, contribute to sea level rise.

Oceans are about 7-8 inches higher than they were in 1900 (3 inches were added since 1993). The rate of rise this past century was greater than any other century in the past 2,000 years. Over 8.6 million Americans live in areas susceptible to coastal flooding, which happens when winds from a coastal storm, such as a hurricane or nor'easter, push a surge of water from the ocean onto land.

High tide floods (also known as "sunny day" floods) occur when the sea washes up and over roads and into storm drains as the daily tides roll in. According to the

NOAA Sea Level Rise Technical Report, high tides driven by rising seas flooded coastal areas more than 500 times in 2022. Nuisance floods are events in which water levels exceed the local threshold (set by NOAA's National Weather Service) for minor impacts. These events can damage infrastructure, cause road closures, and overwhelm storm drains. The additional weight can increase subsidence and erosion effects also. Due to local land subsidence, sea level rise along most of the coastal Northeast is expected to exceed the global average rise. A sea level rise of two feet, without any changes in storms, would more than triple the frequency of dangerous coastal flooding throughout most of the Northeast.

According to the National Flood Insurance Program, "the increase in the expected annual flood damage by the year 2100 for a representative National Flood Insurance Program (NFIP) insured property subject to sea level rise is estimated to increase by 36 to 58% for a one-foot rise" in sea level. Coastal beaches, dunes, salt marshes, and bluffs are likely to experience increased erosion, landward movement, and land loss. In the United States, of the 25 most densely populated and rapidly growing counties, 23 are along a coast facing exposed infrastructure networks, saltwater contamination, immobilization of transportation, and grid failures, resulting in the potential for prolonged disruption of normalcy.[xxxvi]

While conceptually sea level rise is a slow creeping event capable of increasing storm surge and increase the frequency of flooding damage, it can also have far reaching permanent effects on shaping the topology of a coastal region and can carry implications on trade winds and major ocean currents which have direct impacts of the stability of numerous storm patterns across the globe. Rising sea level temperatures can also result in larger areas of hypoxia, or depleted oxygen zones in a water body which often leads to 'dead zones'—regions where life cannot be sustained.[xxxvii] These can carry impacts to the marine industry, fishing, vessel operations, and human life as nearby areas which fuel the expansion of the hypoxia zone can breed toxic algal blooms, the "brain eating amoeba", and various harmful bacteria.

The National Aeronautics and Space Administration (NASA) Sea Level Change Team assessed in November 2022 that the United States would see an average sea level rise of 12 inches by 2050 with the most change concentrated along the Gulf Coast and Southeast.[xxxviii] This rise poses significant potential problems for coastal critical infrastructure and economies. According to the Fourth National Climate Assessment, sea level rise contributes to compounding disasters including higher storm surges and increased precipitation which can flood and destroy coastal communities. These damages are in addition to the negative impacts which sea level rise will have on local fishing, tourist, and public safety activities due to the degradation of existing coastal ecosystems.[xxxix] The threat to critical infrastructure along U.S. coasts is significant. CISA notes the majority of the 104 nuclear power plants in the United States sit along the coast because these facilities rely on the seawater for cooling purposes. Power plants are a fraction of the infrastructure associated with transportation, energy, natural gas, manufacturing, and related industries along U.S. coasts threatened by rising sea levels.[xl]

The Sea Level Rise Technical Report states flooding is rising toward a nationwide average of 3 to 7 days per year by April 2023 and 45 to 70 days per year by 2050. NOAA's projects that, due to regional factors such as ocean currents, coastlines like the East Coast could see seas up to 9.8 feet higher by 2100.[xli]

Severe Storms

A severe storm produces wind gusts of at least 58 mph, hail one inch or larger in diameter, and/or tornadic activity. Flash flooding is also associated with severe storm threats. There are about 100,000 thunderstorms each year in the United States. About 10% of these reach severe levels. Thunderstorms form when warm, moist air rises into cold air and condenses into a rain event with lightning occurring from within the cumulonimbus cloud (aka anvil clouds). Thunder comes from lightning, so, all thunderstorms have lightning as a convective feature which can trigger drought-amplified wildfire activity.[xlii]

Tornado activity from 2008-2021 in comparison with 1991-2010 indicates the seasonal frequency remained the same but the location and intensity of tornadic supercells has shifted to expand "Tornado Alley" to "Dixie Alley" producing larger, longer supercells. Dixie Alley includes Eastern TX, AR, LA, TN, KY, MS, AL, GA, Southern MO, Southeast OK, and the FL panhandle. According to CISA, "each year since 2008 has produced at least $10 billion in U.S. insured damage from severe weather, according to the reinsurance firm Aon. That is more than four times the inflation-adjusted damage rate of the 1980s."[xliii]

In 2022, Iowa experienced its first January tornado since 1967, potentially the furthest northwest tornados ever observed during January. According to NOAA's Storm Prediction Center, during 2022, there were 1,329 preliminary tornado reports. This was above the 1991-2010 U.S. annual average of 1,251 tornadoes. In March 2022 there were 236 tornadoes, which was more than any month's average over the past 14 years. So far in 2023, Maine, Southern California, Guam, and even Washington DC have all reported tornadic activity with expectations that the persistent warming occurring across the nation will yield even more supercells, setting high precedence for new averages. According to data from NOAA's Storm Prediction Center, 2023 has already produced record tornado activity. In January there were 168 tornadoes, fix times the average of 35 tornadoes. in February, there were 55 tornado reports, nearly double the 1991-2010 monthly average of 29 tornadoes. During March, there were 244 tornado reports which is more than triple the 1991-2010 monthly average of 80 tornadoes.

The Storm Prediction Center has released a preliminary count on the number of tornadoes during the month of January 2023. So far, there have been 124 confirmed tornadoes in 16 states, which is the third most on record for the winter month. The tornadoes included 2 in northern California, during one of our many atmospheric river events at the beginning of the month. There was a tornado outbreak in Alabama, Georgia and Mississippi on Thursday, January 12, killing 9 people. Another tornado outbreak on January 24 produced a powerful EF-3 tornado in the Houston suburbs.[xliv]

2023 is ranked third in most January tornadoes, after 1999 and 2017 which had 212 and 137 tornadoes, respectively, which also ranks third for the greatest number of tornado watches in the month of January. According to the SPC, there were a total of 793 severe weather reports which is nearly double the January monthly average (10-year average).[xlv]

Stronger surface heating at higher elevations tied to aridification and earlier snowmelt could result in earlier severe storm events each year the overall atmospheric temperature increases, and drought conditions continue to worsen across the United States. In Texas, Colorado, and Alabama the records for largest hailstone have been broken in the last three years, reaching sizes of up to 6.2 inches in diameter. Insured U.S. hail losses average $8 billion - $14 billion per year, or $80-140 billion per decade. Reports indicate that the 2017 hailstorm caused roughly $2.3 billion dollars' worth of damage and is one of the strongest to ever hit the United States. Texas recorded the single largest hailstone in the state's history in 2021: at 1.26-pounds, measuring 6.4-inch inches in diameter.

Tornado events have become more clustered, with outbreaks of multiple tornadoes becoming more common. As the atmosphere continues to warm at uneven rates, the boundary between airmasses with any cooler air will take on more unstable attributes like larger, more dense hailstones and more damaging winds along the boundary at the surface even if a tornado doesn't fall. Torrential rainfall from a supercell is also likely to become more common as the updraft of the storms builds, allowing for more moisture to become wrapped into the storm cell. Thunderstorms taking on stronger characteristics means more damage to infrastructure, people, plants, livestock, and everything on the surface, but it also means that aviation will see a reduction in capability as the route over or around a storm will close out with larger, more intense systems. Pilots will have to remain grounded until who periods of storms exit or risk their aging aircraft against a strengthening storm core.

Severe storms are likely to intensify in the coming decades with one recent study predicting a nationwide 6.6% increase in the rate of supercells and a 25.8% jump in the area and time supercells stay over land and cause destruction by the year 2100.[xlvi] This is partially driven by an increase in global temperatures and associated additional moisture in the atmosphere which creates the conditions for the formation of severe storms. The impact on the United States will not be uniform – the Southeast will see the largest rise in severe thunderstorm potential whereas the Mountain West will see a decrease in severe storm causing conditions.[xlvii] These storms will bring high winds, hail, and likely increase the number of tornadoes former which will all wreak havoc on critical infrastructure. Between 2000 and 2021, about 83% of reported major power outages in the United States were attributed to weather-related events. From 2000-2021, there were 1,542 weather-related power outages. Most outages were caused by severe weather (58%), winter weather (22%), and tropical cyclones (15%). The average annual number of weather-related power outages increased by roughly 78% during 2011-2021, compared to 2000-2010.[xlviii]

Torrential Flooding

Floods are the most common natural disaster in the United States and about 41 million U.S. residents are at risk from flooding along rivers and streams. River flooding can result from heavy rainfall, rapid snow melt, or ice jams thawing resulting in riverbank damages. Urban flooding refers to flooding that occurs when rainfall overwhelms the local stormwater drainage capacity of a densely populated area causing water to continue to overflow into communities and infrastructure sites. Extreme flooding will continue to be concentrated in regions where humans have built on floodplains or low-lying coastal regions. As extreme weather events increase, risks will extend into new areas.[xlix]

As more evaporation from the land dries soils out, the water is absorbed into the atmosphere as a vapor and that water vapor works to warm the air further by holding in heat regardless of direct sunlight or heat from the surface such as in urbanized areas. When water from intense storms falls on hard, dry ground, or non-permeable surfaces, it runs off into rivers and streams instead of dampening soils. This increases the risk of drought and subsequently can amplify wildfire threat but can also lead to low-lying inundation within populated areas where topography and vegetation has been changed to encourage human infrastructure use.

A flood is an overflow of water onto normally dry land. The inundation of a normally dry area caused by rising water in an existing waterway, such as a river, stream, or drainage ditch. Ponding of water at or near the point where the rain fell. Flooding is a longer-term event than flash flooding: it may last days or weeks.[l]

A flash flood is a flood caused by heavy or excessive rainfall in a short period of time, generally less than 6 hours. Flash floods are usually characterized by raging torrents after heavy rains that rip through riverbeds, urban streets, or mountain canyons and can occur within minutes or a few hours of excessive rainfall. They can also occur even if no rain has fallen, for instance after a levee or dam has failed as runoff over inundates rivers, or after a sudden release of water by a sudden break of an ice jam.

Flash flooding has increased by more than 10% in the Southwest accounting for the greatest increase in "flashiness" among hot spots, while storms in the Northeast are generating about 27% more moisture than a century ago.[li]

A rise in average temperatures at the Earth's surface leads to more evaporation which increases overall precipitation. For every 1.8 degrees Fahrenheit of warming which occurs across the globe, the atmosphere can hold about 7% more moisture.[lii] Heat is released when water vapor condenses to form rain and when rain falls, it brings the warm air down to the surface which further raises the temperature throughout the area. As temperatures increase at the surface, the rate of short-burst heavy rainfall events will increase. The air is on average warmer and moister than it was prior to about 1970 and in turn has likely led to a 5-10% effect on precipitation and storms that is amplified in extreme downpour events.[liii] Flooding is a factor in over 90% of disaster-related property damage in the United States.[liv] New research shows as the baseline temperature annually creeps upward due to moderate to high emission rates, flooding events would become 8% "flashier" by the end of the century. This means that heavy rainfall events are likely to occur quickly and in concentrated areas that could lead to flooding.[lv] Studies show a more than 10% increase in flash flooding in the Southwest U.S. which accounts for the greatest increase in "flashiness" among hot spots. Flooding across Vermont and New York caused by short-burst and heavy rainfall in July 2023 likely caused billions of dollars' worth of damages while destroying critical infrastructure across the region including rail lines, bridges, and roads.[lvi] A 2021 report found that one-fourth of critical infrastructure is at risk of failure by flooding. Nine of the top 10 years for extreme one-day precipitation events have occurred since 1996. These recent floods are a preview of the nature of torrential flooding facing the United States in the coming decades.[lvii]

1,000-year flood events will occur more often due to increased land use and heavier precipitation. The term "1,000-year flood" means a flood of that magnitude (or greater) has a 1 in 1,000 chance of occurring in any given year. In 2022, the United States reported five 1-in-1,000-year flood events in different states causing catastrophic damages. 20-year return floods will more likely occur every two to five years, which brings amplified concerns regarding the emerging flashiness hotspots that will be facing unprecedented challenges with aging infrastructure and outdated flood risk measures. Increases in atmospheric water vapor amplify the global water cycle. They contribute to making wet regions wetter and dry regions drier. The more water vapor that air contains, the more energy it holds. This energy fuels intense storms, particularly over land. This results in more extreme weather events.

As the air becomes warmer and is capable of holding more moisture, severe storm cells which move into a hotter region will be capable of pulling moisture from further up in the atmosphere, in some cases multiple months' worth of rain is being stored as water vapor over the area it has been evaporating from, and the storm cell will produce all those months of rain in a single, hyper-condensed event typically now lasting less than 24 hours and causing wider and wider areas of damage with such forceful downpours that emergency response operations cannot take place until the intensity lessens.

Tropical Cyclones

Tropical cyclone is a more generic term than hurricane. Hurricanes are relatively strong tropical cyclones. Tropical cyclone is a general reference to a low-pressure system that forms over tropical waters with thunderstorms near the center of its closed, cyclonic winds. When those rotating winds exceed 39 mph, the system becomes a named tropical storm. At 74-plus mph, it becomes a hurricane in the Atlantic and East Pacific oceans, a typhoon in the northern West Pacific. In the Northern Hemisphere, tropical cyclones have a counterclockwise circulation of winds near the earth's surface. Tropical cyclones do not have cold or warm fronts attached; those systems are called extratropical cyclones.

Over the 39-year period from 1979-2017, the number of major hurricanes has increased while the number of smaller hurricanes has decreased.

When tropical cyclones encounter land, their intense rains and high winds can cause severe property damage, loss of life, soil erosion, and flooding. The associated storm surge—the large volume of ocean water pushed toward shore by the cyclone's strong winds—can cause severe flooding, additional erosion, and extensive destruction. Warmer oceans produce more evaporation, which means more water is available in the atmosphere as water vapor and allows for more rain. This increased rain releases more heat and amplifies winds around the core of the cyclone.

Flooding damages to energy infrastructure are considerably higher from tropical weather as a combination of overflowing rivers, storm surge, and torrential rains can compound to result in standing water able to reach 1-story deep. Flooding can cause prolonged power outages which can stop elevators, hinder remote entry points, impede refrigeration, disrupt emergency services sites, and damage security features state facilities need to operate. Sudden heavy floodwaters can severely degrade earthen and lined irrigation canals through increased rates of subsidence, erosion, or sediment flows. Flash flooding may carry high levels of raw sewage and debris into waterways and local wells, overwhelming intakes for water treatment facilities and impacting local and regional drinking supplies.

The U.S. Government estimates tropical cyclones will persist throughout the 21st century and continue to cause extensive damage to U.S. critical infrastructure. Although the frequency of these storms may remain the same or even decrease, the tropical cyclones that do form are likelier to reach Category 4 or 5 status and cause devastating damage along U.S. coastlines and interior regions of the country. Current trendlines using predictive climate models conclude that these storms will have more significant rainfall than historic tropical cyclones and when paired with sea level rise, will lead to intense storm surges and associated flooding along coastlines.[lviii] The coming decades will also likely see tropical cyclones impacting U.S. cities further north along the East Coast like New York and Boston at a higher rate. According to recent studies, a decrease in temperature differences between the equator and the poles could weaken the jet stream and allow tropical cyclones to form and intensify at mid-latitudes.[lix] According to the 2021 Sixth Assessment Report from the Intergovernmental Panel on Climate Change, the global frequency of tropical cyclones will likely hold steady or decrease as global warming continues. Among those tropical cyclones, though, the proportion that reach Categories 4 or 5 will very likely increase, impacting cities in the Northeast which are not historically accustomed to that degree of storm severity could have devastating consequences for critical infrastructure in those regions in the coming decades.

More intense and frequent extreme rainfall and associated flooding in many regions including coastal and other low-lying cities, and increased proportion of and peak wind speeds of intense tropical cyclones. This correlates with a recent tropical study by Iowa State University noted a warming climate will increase the number of tropical cyclones and their intensity in the North Atlantic, potentially creating more and stronger hurricanes, according to simulations using a high-resolution, global climate model. The research team ran simulations using the Department of Energy's Energy Exascale Earth System Model and found that tropical cyclone frequency could increase 66% during North Atlantic hurricane seasons by the end of the century. The numbers of tropical cyclones could increase by 34% during inactive North Atlantic hurricane seasons.

In addition, the simulations project an increase in storm intensity during the active and inactive storm seasons. Tropical cyclones were stronger, peak formation of the storms shifted from September to August, and the formation region shifted from the coast of North Africa to the Gulf of Mexico. In the United States, hurricanes caused more than $400 billion in direct economic losses over the historical period 1980-2014, with losses peaking at more than $150 billion in 2005, the year when hurricane Katrina made landfall. The study also finds that already in the present climate, national insurance solutions may be insufficient to effectively mitigate the economic losses caused by extreme weather events in strongly affected developing countries.

For Haiti, as a small island developing state strongly affected by hurricanes, the study shows that even if climate risk insurance were as well developed as in the United States, growth losses would still be six times higher. Hurricane Ian is the third-most destructive storm on record, behind Hurricane Katrina in 2005 and Hurricane Harvey in 2017. Hurricane Maria is ranked 4th and Hurricane Sandy is ranked 5th. The cost of those disasters, adjusted for inflation, stand at roughly $186 billion and $149 billion, respectively. Ian is likely to eclipse the $114 billion mark and numbers continue to be refined.

NOAA recently released a new explanatory guide: This information could be a useful guide to distribute to staff, as it succinctly covers the dangers of hurricanes and how to plan for them. 57% of fatalities during tropical cyclones have been caused by storm surge.

- Storm inundation levels during hurricane surge events will increase due to sea level rise, anticipated to rise by about 2 to 3 ft by 2100.
- Total numbers of Atlantic tropical storms and hurricanes combined are projected to decrease by 15%, but with uncertainty; a minority of studies project an increase.
- Strongest winds of tropical storms and hurricanes are projected to increase about 3%.
- Due to human-caused climate change, precipitation rates within tropical storms and hurricanes are projected to increase by about 15%. And the number of Atlantic hurricanes reaching Category 4 or 5 intensity are projected to increase about 10%.

NATIONAL SECURITY IMPLICATIONS

Impacts on conflicts and instability

Climate change and associated extreme weather events can have an indirect but real impact on conflicts and instability by intensifying existing tensions or creating new disputes over resources and territory. A 2019 study from Stanford University found climate change contributed to between 3% to 20% of conflicts over the last century with the potential influence set to increase substantially due to warming global temperatures.[lx] Extreme weather events, like prolonged droughts and sea level rise, create conditions which weaken existence governing institutions and force economic, societal, and resource disruptions which lead to conflict within states and between states.[lxi] [lxii]

Within states, the downstream impacts of climate change and extreme weather events can empower violent non-state groups while weakening the authority of the state. Poor government response following natural disasters, especially in underdeveloped countries with a lack of adaptive capacity, likely diminishes trust in those in power and provides non-state actors an opportunity to garner support by securing and distributing aid and increasing recruitment by offering alternative livelihoods and incentives. Climate change also leads to a rise in inhospitable environments which become ungoverned spaces as weak central governments lack the resources to exert control or struggle to address the multifaceted challenges posed by extreme weather events.[lxiii] Ungoverned spaces become havens for transnational criminal organizations, terrorists, and other armed groups from which they can operate illicit enterprises, challenge state authority, or take part in internationally directed terrorism. The Sahel in West Africa is a primary example of how climate change induced desertification created wide swathes of largely if not wholly ungoverned territory in Libya, Algeria, and Mali where extremist groups can thrive including Boko Harm and groups associated with both al Qaeda and ISIS.[lxiv] This region now accounts for 43% of all global terrorism deaths based on figures from 2022 which is in part linked to the stressors from climate change.[lxv]

The changes of interstate conflict also rise due to factors caused by climate change and extreme weather events. The U.S. Intelligence Community's 2023 Annual Threat Assessment predicts resource conflicts will intensify as access to freshwater resources and arable lands decrease while changing sea access creates new geopolitical flashpoints.[lxvi] For example, the Arctic Circle is becoming more hospitable and navigable as changing climate patterns lead to less sea ice, open navigable sea routes, and open access to potentially large swathes of untapped natural resources. The United States, Russia, and China, among other states, are vying for dominance in this region and all are likely to increase deployments of commercial and military resources to the Arctic Circle in the coming decades. A surge in activity in the region also has the potential to inflame existing tensions between the United States and Russia or China as competition for Arctic Circle resources and dominance becomes a geopolitical focus for each country.[lxvii]

Impacts on migration

The U.N.'s International Organization for Migration defines climate migration as communities of people who are forced to resettle within their country's borders, regionally or internationally due to the effects of climate change and weather-related disasters. From 2013 to 2022, weather-related events displaced approximately 2 million people annually in Central and Latin America alone.[lxviii]

Climate change and weather-related disasters will continue to disrupt both international and national migration patterns due to the destruction of homes, livelihoods, and infrastructure that force populations to flee their communities and seek refuge in areas less significantly impacted. While the majority of climate migrants resettle in different areas of their own country, regional and international migration is also increasing.[lxix] Government leaders saddled with debt and decreasing government services, will also have to contend with costly and unpredictable weather-related disasters and recovery efforts. In the United States, weather-related disasters are expected to increase government debt by approximately $2 trillion annually by the end of the 21st century, according to the White House Office of Management and Budget.[lxx] When governments fail to act effectively to mitigate the challenges exasperated by climate disasters, economic and political instability often ensues.

Weather patterns and geography will facilitate different migratory patterns throughout the world; however, for the United States, Atlantic hurricanes traversing the Gulf of Mexico and the Caribbean Sea will impose the greatest migratory security risks at the southern U.S. border.[lxxi] Climate migration compounded by the effects of economic hardship, political instability and violence in Latin America and the Caribbean has overwhelmingly contributed to the increase in legal and illegal migration in the southern U.S.[lxxii]

A significant extreme weather event in the Western Hemisphere could prompt larger groups of migrants to the U.S. Southern Border, providing a strategic opportunity for adversarial nation states and non-state actors. Increasingly sophisticated human trafficking networks and the diversified routes and methods used to smuggle people and goods, could likely present significant challenges to U.S. national security and the private sector. Partnerships between the public and private sectors to create innovation mitigation strategies and protective solutions will be crucial to the security of the U.S. Southern Border.

Impacts on defense industrial base

The defense industrial base (DIB) is vulnerable to the impacts of climate change which causes associated operational issues for the armed services. In an ever-evolving national security environment, a strong DIB is a strategic advantage for the United States. However, climate change and associated extreme weather events can challenge the ability of the DIB to support the needs of the U.S. Department of Defense (DOD) and the warfighter. This is an international challenge because the DIB extends beyond U.S.-based contractors providing platforms and services to the DOD but also includes foreign companies supporting U.S. forces based abroad and facilities operated by foreign states where the U.S. military has an operational presence.[lxxiii] The DOD is continually assessing its supply chain resilience and actively strengthening the DIB to meet national security needs. The DOD now includes extreme weather events in its reports on the health of the DIB. In addition to direct damage to DIB companies, research and development of future capabilities, products, and weapons systems can all suffer due to the fallout of extreme weather events as defense contractors repair damages to facilities and infrastructure. The current just-in-time production posture of the DIB offers limited resiliency and ability to reconstitute after a destructive extreme weather event. Large U.S. defense contractors recognize the scale of the problem. For example, Lockheed Martin released a report detailing climate risks and opportunities for the company. The report notes that extreme weather events could isolate company assets by destroying or degrading infrastructure Lockheed Martin relies on to supply customers and receive parts from third-party subcontractors.[lxxiv]

Beyond the potential impacts on the DIB, extreme weather events pose challenges to U.S. military operations globally. The U.S. military maintains over 5,000 facilities globally, of which 1,700 are on or near coastlines and face the threat of sea level rise and associated flooding.[lxxv] Norfolk Naval Shipyard, one of four U.S. Navy shipyards which can maintain and repair nuclear powered submarines and aircraft carriers, is one of the premiere U.S. military facilities threatened by rising sea levels and associated flooding. Several instances of flooding at the facility damaged sensitive equipment and future estimated storm surges could compromise the drydocks and severely damage ships undergoing repairs.[lxxvi] Future damage to facilities like Norfolk Naval Shipyard could have real operational impacts on the U.S. military in the future by limiting the availability of critical platforms and systems needed to sustain global missions.

Impacts on economic and financial sector

Extreme weather events have been having significant impacts on the U.S. financial service industry, including insurance companies. These impacts are closely related to U.S. national security due to the critical role of the financial sector in the overall stability and resilience of the economy. The impacts include business disruptions, increased insurance claims, infrastructure damages, and asset exposure. Given the intertwined nature of the financial services industry with the broader economy, these impacts can lead to economic downturns, which in turn can affect the profitability and stability of financial institutions. For example, events such as hurricanes, floods, wildfires, and tornadoes can result in substantial property damage and losses. This leads to a surge in insurance claims, putting significant financial strain on insurance companies. If these companies are unable to manage the increased claims, it may lead to reduced capacity and increased premiums, affecting businesses and households alike. The frequency and severity of such extreme weather events can strain the financial reserves of insurance companies. Catastrophic events can lead to a sudden depletion of resources, impacting their ability to pay claims promptly and leaving them vulnerable to financial instability.

In addition, financial institutions, including banks and investment firms, have substantial assets exposed to various industries and properties. Extreme weather events can lead to physical damage and devaluation of these assets, affecting the overall stability of the financial system. Finally, extreme weather events can damage critical infrastructure, such as transportation systems, power grids, and communication networks. These damages can lead to a disruption of business operations, leading to lost revenue for companies and uncertainty in financial markets. This disruption can have cascading effects on the overall economy and national security if critical services and industries are impacted.

Impacts on physical infrastructure

Extreme weather events affect the physical infrastructure that operate and deliver services critical for daily life. Disruptions to transportation, energy, and water sources and infrastructure can hinder the government's response to emergencies and external threats.[lxxvii] [lxxviii] Roads, bridges, and hospitals are vital to emergency response following an extreme weather event and must be able to withstand the changing climate. According to First Street Foundation, about 25% of all critical infrastructure in the United States is at risk of becoming inoperable due to flooding, including an estimated 23% of all roadways in the country.[lxxix] Flooding in Pakistan in 2022 damaged more than 8,000 miles of roads, approximately 410 bridges, and over 30 rail stations, severely hindering evacuations, emergency response, as well as access to medical facilities.[lxxx] [lxxxi] More frequent, stronger weather systems that cause severe damage will likely inundate medical services, as well as the supply chains for medicine and medical equipment. Energy and water are also essential to the sustainability of these services.

Impacts on supply chains

Extreme weather-related disruptions to the global supply chain are often most impactful when physical infrastructure such as distribution centers, production facilities, warehouses, and logistics routes experience damage. The current highly interdependent supply chain relies heavily on original equipment manufacturers (OEMs), companies that supply components that are used in the production of goods by other manufacturers. Historically, climate-linked operational disruptions at OEMs have had significant effects on downstream supply chains which has resulted in production interruption, shortages, delays, and increased costs of critical goods. Often, companies rely on singular production sites with minimal or no alternatives and are unable to maintain continuity in their manufacturing after a disaster. After an extreme weather event, OEMs may be dependent on government aid, an available workforce, and restoration resources to begin production again, delaying all further supply chain components including additional manufacturing, assembly, shipping and transportation, and delivery to end consumers who then often experience a price increase. Transportation logistics is a key node to maintaining the flow of goods and services, however, even its infrastructure that is built to withstand extreme weather events, is starting to become more vulnerable as stronger storms become more frequent. Rising sea levels and flooding will affect ports and their associated intermodal transportation such as trucks and rail networks. In 2012, Hurricane Sandy caused the Port of New York and New Jersey to close for nearly a week which diverted multiple cargo vessels and resulted in a $130 million revenue loss.[lxxxii]

Two industries most at risk for high impact supply chain disruption due to extreme weather, and whose shortages and delays could pose immense national security risks for the United States, are semiconductors and pharmaceuticals. The daily life of most communities is highly reliant on semiconductor component products, or microchips. The globe's dependency on Taiwan, the center of the industry, has been tested in recent years in addition to the U.S. dependency on chip manufacturing facilities in Texas, after disparate weather events halted the production of essential goods across numerous sectors resulting in a worldwide crisis. Taiwan's drought concerns impacted not only the water supply of chip manufacturing sites, but also its hydroelectric power supply. In Texas, unexpected winter storms caused power outages at their sites.[lxxxiii] Similarly, the pharmaceutical industry relies on active pharmaceutical ingredients (APIs), the raw materials included in a majority of their products, making it consistently at risk for disruptions due to extreme weather impacting API suppliers, which are often located in South and East Asia. Cost-effective drugs tend to be most at risk, as many of the cheapest products are manufactured in the region, increasing vulnerability due to frequent natural disasters in the area.[lxxxiv] Road blockages from damage or debris can hinder access to manufacturing facilities, suppliers, and warehouses, furthering disruptions and delays to the supply chains of critical supplies that are vital to national and economic security.

Impacts on healthcare and public health

Extreme weather events have a negative impact on overall health, can directly cause injury, illness, and even death, and overwhelm the health infrastructure making it difficult for patients to receive medical care. It is crucial for communities to prepare individuals to protect themselves from extreme weather events and ensure that healthcare systems have contingency plans in place to address the surge in cases when extreme weather events inevitably occur.

Extreme weather affects the social and environmental determinants of health including air quality, safe drinking water, sufficient food, and secure shelter. For example, worsening air pollution levels from wildfires place additional stress on the lungs causing and exacerbating respiratory conditions, droughts and flooding impact food and water supply, and hurricanes damage housing. Extreme weather events can also directly cause injury, illness, and even death and tend to also have cascading effects such as the spread of infectious disease due to increases in food-, water- and vector-borne diseases. Additionally, extreme weather events can be traumatic for those affected, leading to mental health issues such as depression, anxiety, and post-traumatic stress disorder.[lxxxv]

Communities can minimize the impact of extreme weather by encouraging individuals to take precautions. For example, individuals should remain indoors when the air quality is in an unhealthy range, have an adequate supply of food and water, and seek shelter during hurricanes or during periods of extreme heat or extreme cold. Most importantly, communities should provide these services for those who may not have the resources to take precautions.

Extreme weather events often also degrade the medical community's ability to provide adequate care as the surge in injuries and illnesses can overwhelm healthcare infrastructure. An increase in patients seeking medical attention puts a strain on ambulances and emergency medical technicians, affecting response times. Furthermore, extreme weather events can decrease staffing levels at hospitals and disrupt the supply chain of essential medications and medical equipment, delaying and in some cases denying treatment to patients.

Areas with weak health infrastructure will be the least able to cope without assistance to prepare and respond to extreme weather events. Extreme weather driven health risks are disproportionately felt by the most vulnerable and disadvantaged, including women, children, ethnic minorities, poor communities, migrants or displaced persons, older populations, and those with underlying health conditions, further widening existing health inequalities between and within populations. Communities should invest in the resiliency of healthcare systems enabling them to adequately plan and prepare for extreme weather events and provide additional support to vulnerable populations.[lxxxvi]

CASE STUDIES

Pharmaceutical Supply Chain Case Study

The Impact of Hurricane Maria on U.S. Pharmaceutical Availability

In 2017, the United States experienced a critical shortage of Small Volume Parenterals (SVPs) when Hurricane Maria caused Baxter International's manufacturing facilities in Puerto Rico to temporarily shut down. These manufacturing facilities specifically manufactured MINI-BAG and MINI-BAG Plus Container Systems which are used to compound or admix a medication or to aid in the delivery of a medication. As a result of this supply chain disruption, hospitals throughout the United States were forced to use less efficient alternatives lowering the standard of care for patients. While the pharmaceutical industry cannot eliminate all risks to production, by implementing industry best practices and collaborating with government agencies they can adequately prepare for the persistent and escalating threat of extreme weather.[lxxxvii]

Best Practices for the Pharmaceutical Industry

To complete this study, resiliency and operational experts at two global pharmaceutical companies that were severely impacted by Hurricane Maria were interviewed. Due to their resiliency efforts, one pharmaceutical manufacturer was able to resume limited production within one week and return to normal production within six months while the other was able to return to normal production within three days. Since Hurricane Maria, both companies have further prioritized resiliency efforts improving their monitoring for extreme weather, strengthening physical infrastructure, promoting supplier and wholesaler resilience, decentralizing power, preparing and assisting their workforce to recover from extreme weather, building in redundancy into their communications, conducting vulnerability assessments, and leveraging their national and international networks.[lxxxviii]

- *Monitoring for Extreme Weather.* Both pharmaceutical companies have mapped their critical path identifying each asset from the sourcing of raw materials to the delivery of final drugs. They incorporate meteorological data from various open sources and utilize commercial software toolsets to aggregate and display the information for analysts to evaluate. In addition, both companies utilize an automated alert system to ensure that all extreme weather events and their potential impact on the supply chain are fully considered and communicated. One company shared how they have a dedicated weather team that works closely with their global logistics supply-chain team and together they use this information to drive decisions about which routes to take and when to hold or expedite the shipment of cargo.

- *Strengthening Physical Infrastructure.* Both pharmaceutical companies withstood the effects of Hurricane Maria with minimal structural damage to their facilities due to the preemptive fortification of buildings, particularly roofing. However, there was significant damage to the roads and bridges surrounding their facilities prompting one company to mobilize smaller vehicles to transport final products, supplies, and fuel.[lxxxix]
- *Promoting Supplier and Wholesaler Resilience.* While the pharmaceutical companies have significant control over their own manufacturing facilities, they often have limited insight into their raw material suppliers, many of which are located in South and East Asia, regions that are highly vulnerable to extreme weather. One company identified that they approach this vulnerability by asking vendors to complete a procurement questionnaire which solicits information about the supplier's resiliency posture and use this response in vendor selection decisions. In addition, they include clauses in their supplier and wholesaler contracts that stipulate business continuity planning. Another company mitigates supplier vulnerabilities by carrying additional inventory of raw materials, often storing a 30-90 day supply of raw materials which are prone to supply chain disruptions, balancing inventory based on historical and seasonal trends. In an effort to distribute the burden, this company is actively exploring options to incentivize wholesale distributors to maintain a rotating stockpile, providing a buffer when manufacturing is temporarily disrupted and creating an additional contingency source of critical pharmaceuticals in the event of an emergency.
- *Decentralized Power.* During and immediately following Hurricane Maria, both pharmaceutical companies maintained backup diesel generators in all facilities on the island to supply power during the electric grid interruptions with one company holding seven days of fuel at all times.[xc] Since Hurricane Maria, one company identified additional steps taken to permanently decentralize power by installing small solar power generators throughout their property and will soon have a fully operational independent electric grid that can be coupled with commercial power from the island.
- *Preparing and Assisting Workforce Recovery.* In the aftermath of Hurricane Maria, both pharmaceutical companies defined playbooks and timelines for recovery. One company detailed how they provided potable water, portable generators, and fuel to employees to assist in their personal recovery and support their return to work. This company has since developed an employee preparedness program to ensure that employees have the knowledge and resources to recover from extreme weather events, such as providing

backpacks filled with emergency items. In addition, they implemented an employee assistance program to help employees with their individual circumstances which includes transportation, housing, and even medical assistance for family members to facilitate their employees return to work. Because extreme weather events can be traumatic, this company also offers a counseling program to ensure that their employees are mentally ready and equipped to return to work.

- *Communication Redundancy.* Due to disruptions in service from local telecommunications providers during and after Hurricane Maria, both pharmaceutical companies relied on satellite communications to conduct accountability and distribute information to their employees. Since then, both companies have made advances in providing employees with multiple forms of communications including satellite phones and radios for receiving AM transmitted company notifications and developed autonotification systems to broadcast information to employees. One company has also established communication hubs throughout the island, provided mobile cell phones, tablets, and laptops with hot spots and secured primary and secondary internet providers to enable telework. This company also gives site leaders 72 hours to complete initial accountability and follow-up with daily headcounts during which employees are encouraged to communicate not only their status but also any personal response and recovery needs.
- *Vulnerability Assessments.* A recurring theme communicated by both pharmaceutical companies was the need to identify vulnerabilities, define resiliency, and adapt to changing threats. One company shared that they conduct regular crisis exercises to ensure that their processes and procedures are effective when responding to and recovering from extreme weather events. After Action Reports highlight areas that need to be improved and how to address exposed vulnerabilities.
- *Leveraging their Network.* Prior to Hurricane Maria making landfall, one pharmaceutical company shipped finished products to their domestic warehouses to mitigate the impact of a potential shutdown. This company also worked with the Food and Drug Administration (FDA) to secure regulatory discretion for the temporary special importation of certain products from their facilities in Ireland, Australia, Canada, Mexico, England, Italy and Brazil to mitigate the impact to U.S. hospitals.[xci]

Enabling a Whole-of Government Response

After a shortage has been identified, government agencies can mobilize to facilitate the production of final drugs and distribution to end-users. The Department of Health and Human Services (HHS) Supply Chain Control Tower (SCCT) Program enables end-to-end visibility for supply chain monitoring in response environments. The SCCT allows for scenario modeling, demand forecasting, and gap prioritization as well as support capacity planning, acquisition strategies, and targeted distribution. It also creates visibility on end-to-end inventory levels, manufacturer capacity, distribution flows, and point-of-care consumption. SSCT partners with each of the agencies below to address potential shortages.

- *The Department of Health and Human Services (HHS),* Food and Drug Administration (FDA) field inspectors conduct inspections of the manufacturing facilities once made aware of an impending shortage. If the impending shortage is confirmed, FDA determines the extent and assists in identifying the root cause and restoring production. The FDA can also mitigate shortages caused by discontinuance or interruption in manufacturing by extending expiration, easing quality assurance requirements, and/or requesting other entities to increase production or start new production.[xcii] HHS's Administration for Strategic Preparedness and Response (ASPR) promotes "warm basing" by encouraging pharmaceutical companies to maintain production readiness by reducing overhead, utilizing emerging technologies, and incentivizing government agencies and hospitals to buy their products to keep machinery running and labor employed. ASPR also deploys incident management teams during and after extreme weather events to assess needs and distribute resources accordingly.[xciii]
- *The Department of Transportation (DOT)* can implement temporary transportation solutions, often providing emergency waivers and special permits to enable logistical agencies to operate at a heightened tempo. The Federal Aviation Administration can impose flight restrictions to give priority to response and recovery operations. The Federal Highway Administration can assist in repairing or reconstructing damaged highways. The Federal Motor Carrier Safety Administration and the Federal Railroad Administration can temporarily lift safety regulations, including hours of service, from interstate motor carrier drivers and operators and trains providing emergency relief. The Maritime Administration maintains the National Defense Reserve Fleet which can stage equipment and personnel and transport cargo. Lastly, the Pipeline and Hazardous Material Safety Administration can issue exemptions for pipeline operation and hazardous materials transportation.

- *The Department of Homeland Security's (DHS)* Federal Emergency Management Agency (FEMA) Public Assistance Program can provide supplemental grants to state, tribal, territorial, and local governments, and certain types of private non-profits to assist communities in quickly responding to and recovering from major disasters, including extreme weather. This grant program helps areas cover the cost of public infrastructure restoration, debris removal, and life-saving emergency protective measures after a damaging weather event. Additionally, FEMA provides assistance for hazard mitigation measures during recovery to protect damaged areas from future events. Private sector organizations such as pharmaceutical companies can proactively collaborate with their state, territory, tribe, or local government to notify them of any facility public access roads that may be compromised during a weather event and need expedited clearing as part of the community's restoration plan in order to transport critical materials.
- *The Department of Energy's (DOE)* Office of Cybersecurity, Energy Security, and Emergency Response (CESER) coordinates DOE's response to hazards facing the energy sector. When a potential disaster is identified, CESER dispatches responders to the region's State Emergency Operations Centers and the FEMA Regional Response Coordination Center to coordinate with local officials and industry representatives. Once a disaster occurs, DOE responders provide subject matter expertise to help state and industry partners assess the disaster's impacts, restore energy systems, and identify additional needs. Additionally, CESER holds daily calls with sub-sectors like electricity, oil, and natural gas to coordinate a response while also providing routine situation reports and analysis of impacts to the energy sector. When extreme weather results in prolonged restoration, DOE responders work with utilities, state agencies, FEMA, and the U.S. Army Corps of Engineers to assure materials, equipment, and any necessary assistance are mobilized to obtain temporary power.
- *The Department of Commerce (DOC)* can negotiate and advocate for trade agreements that facilitate the flow of pharmaceutical ingredients and final drugs across borders. DOC often engages in bilateral and multilateral engagements to address trade barriers, such as tariffs and quotas, that hinder the flow of supply chains. DOC can also implement policies and initiatives to promote domestic manufacturing capabilities such as providing financial incentives, tax breaks, and grants to businesses that can ramp up production to offset shortages.

Enduring Challenges and Opportunities for Private-Public Collaboration

The U.S. Government's understanding of critical shortages is largely reliant on final drug manufacturer or end-user (hospitals, physicians, pharmacists) notification. Once the impending shortage is confirmed, HHS, DOT, DHS, DOE, and DOC can step in to mitigate the impact to patients. While mitigation tactics are highly effective in easing the impact of shortages, they take time to implement. The U.S. Government and pharmaceutical industry could both benefit from increasing the time for mitigations by developing an understanding of critical dependencies and risks within the global supply chain and planning for potential disruptions.

Concealed Transparency and Analytical Insights

Pharmaceutical shortages can result from disruptions in final drug production as demonstrated by Hurricane Maria but are also heavily impacted by the sourcing of raw materials. Pharmaceutical drugs are made from Active Pharmaceutical Ingredients (APIs) which produce the intended effects and "excipients" which help to deliver, stabilize, or increase the absorption of APIs. Roughly 80% of APIs are sourced from South and East Asia, regions likely to repeatedly experience cycles of extreme heat as the global temperature rises. Studies have shown that with a single °C degree rise in temperature manufacturing output decreases 1-3% as machinery fails and labor is either absent or significantly slower.[xciv] With increasing temperatures these regions also become vulnerable to cyclones, typhoons, and flooding that can shutdown manufacturing facilities for extended periods and disrupt transportation routes.

The pharmaceutical supply chain lacks transparency particularly when it comes to sourcing raw materials. While many pharmaceutical companies have developed a robust understanding of their critical paths and the environmental (and often social, political, and economic) risks each node is susceptible to, they are often unaware of the demand placed on each node. In addition, pharmaceutical companies often buy their raw materials from only one source to achieve contractual cost savings creating a critical dependency. The pharmaceutical industry could benefit from having more information about the demand that their suppliers face and the distribution routes utilized so that they can consider the impact of potential disruptions and make better sourcing decisions.

Pharmaceutical companies are understandably reluctant to publicly declare their critical path as this information could be exploited by competitors. However, they may be willing to disclose sanitized information about raw material suppliers and distribution networks through a secure platform to a third party which could then compile this information developing an overall understanding of the complex web of critical paths. In return, the third party would be able to foresee potential disruptions and tip both the pharmaceutical companies and federal agencies to impending shortages giving them more time and options to sustain the supply chain and mitigate the impact to patients. For example, multiple pharmaceutical companies may not realize that they are competing to acquire a raw material that is produced at a factory in India that is experiencing extreme heat and likely to suffer from catastrophic flooding during the upcoming monsoon season potentially halting operations. In this situation, the third party could provide advance warning to the pharmaceutical companies that may be impacted by a disruption and the U.S. Government could assist them in finding alternative sources, facilitating shipments prior to the extreme weather event, and restoring production at the affected manufacturing facility.

Contingency Planning

Pharmaceutical manufacturing requires a high level of precision to ensure that the final drug product is consistent with quality requirements as small variations and contamination can have a significant impact on efficacy and safety. Due to the complexity, manufacturing facilities typically focus on producing one drug at a time often taking weeks and sometimes months to set-up production making it difficult to switch to another drug. Pharmaceutical companies also typically use Just-In-Time (JIT) inventory practices as it helps them achieve cost savings in storage and transportation and minimizes the risk of having to discard expired inventory. Therefore, it is extremely difficult for pharmaceutical companies to develop the reserves needed to prevent a shortage. Pharmaceutical drugs that are at a high risk of experiencing a shortage should be identified through data analytics for contingency planning. Once identified, the U.S. Government can find back-up suppliers and negotiate agreements in advance so that those pharmaceutical companies can quickly increase or start new production.

DHS and HHS jointly manage the Strategic National Stockpile (SNS) which receives the FDA's Essential Medicines, Medical Countermeasures, Critical Inputs List and then prioritizes the procurement and storage of the highest priority antibiotics, chemical antidotes, antitoxins, life-support medications, IV administration, airway maintenance supplies, and medical/surgical items. The Biden Administration's hopes to expand the SNS with E.O. 14017, which establishes a "virtual" stockpile by negotiating contracts with API suppliers and final drug manufacturers to hold surplus together for surge manufacturing capacity rather than relying on the centralized SNS.[xcv] E.O. 14017 also mandated that HHS collaborate with private entities to select 50-100 critical drugs from the FDA's Essential Medicines, Medical Countermeasures, Critical Inputs List to onshore. HHS was additionally tasked with developing technologies to increase domestic API manufacturing capacity and convening pharmaceutical supply chain experts to develop a resiliency framework.

Both the stockpiling and onshoring efforts dictated by E.O. 14017 are centered around the Essential Medicines, Medical Countermeasures, Critical Inputs List which currently focuses on drugs that are medically necessary to have available in adequate supply which can be used for the widest populations to have the greatest potential impact on public health. However, the criteria currently does not specifically address raw materials and final drugs that are at a high risk of experiencing supply chain disruptions.[xcvi] FDA's efforts could benefit from evaluating additional information to develop a more timely and accurate Essential Medicines, Medical Countermeasures, Critical Inputs List which takes into consideration potential supply chain disruptions.

Prioritizing Resilience

As the global temperature rises, extreme weather will become more common and less predictable. The pharmaceutical supply chain is not only vulnerable to hurricanes and cyclones but also extreme heat, extreme cold, wildfires, prolonged drought, sea level rise, and torrential flooding. By increasing the transparency of the global pharmaceutical supply chain, the pharmaceutical industry and federal agencies can work together to proactively address vulnerabilities before they reach the point of crisis. As endorsed by the outcomes of numerous industries impacted regularly by extreme weather, the continuous establishment of opportunities to create partnerships is key to mitigate critical storages and sustain the supply chain. Building resiliency into the global pharmaceutical supply chain can protect U.S. patients from degradation of care and provide the U.S. Government with a powerful tool to promote global stability and gain a diplomatic advantage in an era of strategic competition.

Taiwan Case Study

Case Overview

Extreme weather will continue to have increasing negative impacts on the supply chain of critical infrastructure sectors related to the national security of the United States. These impacts are caused by shifting weather patterns and intensities across regions encompassing the global supply chain. In 2021, a drought in Taiwan caused by a lack of rainfall due to shifting typhoon patterns nearly crippled the global semiconductor supply chain. Taiwan avoided shutting down its semiconductor fabrication plants by implementing stringent restrictions on virtually all other industries in the country. This case study reviews the semiconductor industry's steps to decrease water consumption and work with the government to build resilience into their business operations. In addition, the case study highlights the devastating effect a lack of extreme weather can have on locations reliant on extreme weather, an area often overlooked when exploring shifting weather patterns and climate change. Extreme weather events will play a more significant role in supply chain stability as shifting weather patterns impact critical regions with changing weather types and intensities. America's reliance on Taiwan for most semiconductor fabrication puts all 16 of CISA's critical infrastructure sectors at risk, given the extreme dependence on the ability to replace or enhance the technology required in the industries, from personal electronics and office supplies to advanced supercomputers.

Taiwan Climatology

Taiwan's climate is predominantly subtropical, with summer lasting from April to October at its longest point with an annual high of 70 degrees and a warm current in the surrounding waters.[xcvii] This places Taiwan in the position to be heavily dependent on rainwaters for farming, drinking, and operations of heavy machinery requiring liquid cooling. As the global atmosphere continues to warm at uneven rates, Taiwan has noted a significant swing in the reliance of rainfall causing more impactful droughts. In 2021, a cumulation of dry years came to international notice when most of the reservoirs widespread dropped to 20% or less, with some below 10%.[xcviii] Typhoons are significantly impacted by the warming climate as recent studies show, globally the expectation is for fewer typhoons overall but those which do form will produce greater swings in precipitation and more damaging wind events.[xcix] Located along the main typhoon path off the East Asian continent in the WNP, Taiwan is one of such places and often receives the bulk of its ample annual total rainfall amount, approximately 2500 mm (98 inches) for the whole island, in the typhoon season. The typhoon season in this part of the world is year-round.[c] At the peak of concern in 2021, the Baoshan No. 2 Reservoir in Hsinchu County, one of the primary water sources for Taiwan's $100bn semiconductor chip (hereafter referred to as "chip") industry, the water level was at the lowest it has ever been - only 7% full. Around 90% of the most advanced chips are manufactured in Taiwan.[ci] This resulted in a reduction of water allocation to agriculture and a public outcry that industry was misusing a limited resource, pressing the need for a climate resilient investment to maintain future operations as Taiwan continues to experience frequent droughts and greater uncertainty in global water retention unfolds. New studies indicate that despite more water retention capabilities at the surface (more reservoirs), there is less water available than the historical average as the atmosphere warms and can hold more evaporated moisture from the earth

Extreme Weather Impacts on Taiwan's Semiconductor Chip Industry

Changing weather patterns in Taiwan and the resulting disruption to the chip industry has negatively impacted several U.S. critical infrastructure sectors. To increase National Security resilience within the country's supply chain for the 16 critical infrastructures and decrease the threat of disruption to chip acquisition and increase resilience within its logistical stockpile, the United States will need to diversify its chip production vendor locations, along with its supply chain, and be mindful of the susceptibility to and reliance on specific required environmental conditions weather for appropriate production at each site. The United States will also need to maintain focus on the changes to weather patterns in locations where critical infrastructure sectors are located as well as the locations of their supply chain. Purposefully building internal supply chain diversity via geographic variety and vendor redundancy will decrease the dependence on singular vendor disruptions cashed by extreme weather, thereby increasing overall national resiliency and, in turn, national security.

The global chip supply chain was impacted by an acute shortage in 2021 due to a rapid increase in demand from shifting purchasing patterns during the pandemic, compounded by changing weather patterns leading to the drought in Taiwan. The drought reduced the needed water required to fabricate the chips in the country that produces more than 90% of the world's most advanced chips. Taiwan is home to the Taiwan Semiconductor Manufacturing Company (TSMC), the world's largest semiconductor producer.[cii]

In 2021, Taiwan was hit with one of the worst droughts in its history. The lack of rainfall forced the country to restrict already limited water usage to five days a week and send water tankers to supply residents in some portions of the island. Chip fabrication plants utilize excessive volumes of water as part of the fabrication process; TSMC used 150,000 tons of water daily before implementing recycling practices following the drought.

For years, Taiwan relied on typhoons to replenish the island's water supply. With shifting weather patterns due to climate change, typhoons are affecting the island less frequently, causing more common and more intense periods of drought. Taiwan's reliance on typhoons and the increasing likelihood of droughts enhances the risk of disruption to chip production. America's reliance on Taiwan for the majority of chip fabrication puts all sixteen critical infrastructure sectors at risk, given the extreme reliance on the ability to replace or enhance the technology required in the industries, from weapon systems, personal electronics and office supplies to advanced supercomputers.

To limit its water use, TSMC set up its own water recycling plant in 2021. And it and many of Taiwan's biggest chip factories are cutting down water use by 10 to 15%

this year - unfortunately, at a time when global demand for chips is growing.[ciii] A new facility has been built in Hsinchu to deal with the current drought, but it can only treat 13,000 tons of water daily, a drop in the bucket compared to the 170,000 tons used each day just by Hsinchu Science Park, where many semiconductor makers are based.[civ]

Struggling to ensure supplies, the government stopped irrigating more than 74,000 hectares of farmland last year. At NT$11 (U.S.$0.39; £0.27) a ton, Taiwan's water rates are the second lowest among 35 countries and territories surveyed; half the cost of South Korea's rate, four times lower than that of the United States and six times lower than costs in the United Kingdom.

Instead, it's looking at Taiwan's surrounding waters for solutions, planning to build more seawater desalination plants. Most are located in outlying islands, with only three on Taiwan's main island. A new facility has been built in Hsinchu to deal with the current drought, but it can only treat 13,000 tons of water daily, a drop in the bucket compared to the 170,000 tons used each day just by Hsinchu Science Park, where many semiconductor makers are based."[cv]

The following sections cover the weaknesses, strengths, lessons learned, and outlook of the response and management of the changing weather patterns in Taiwan from the resulting droughts in 2020-2021 and the droughts' impact on the global chip supply chain.

Weaknesses

The government's prior inattention to the need for resource conservation measures encouraged wasteful water usage. The Taiwanese government maintained tariffs that kept water prices artificially low, which did not incentivize industries and households to properly value the water they used. Wasteful water usage was compounded by Taiwan's generally poor water infrastructure. Long experience with plentiful cheap water allowed the government to deprioritize finding leaks or making regular infrastructure improvements. When drought came, in addition to the immediate water shortage issue the government was also faced with the need to fund long delayed and costly infrastructure upgrades.

The government's immediate response to the drought was to prioritize chip production over agriculture and other industries. The Taiwanese government introduced water rationing for other industries and households, and raised water prices to fund the repairs the government discovered were necessary to better conserve water. The lack of planning forced the government to make decisions quickly, without the time for adequate study or public consultation. As an immediate fix the government paid farmers to leave fields fallow. However, this measure may dismantle the existing market for those farmers by shifting their regular customers to other sources. The result could lead to years of depressed income for the farming industry and further weaken Taiwan's domestic farming capability. For a country with high population density and already insufficient food production, this unintended consequence of short-term policymaking could have future repercussions the government did not fully consider.

Lessons Learned & Best Practices

Chip companies and their supply chain ecosystem increasingly represent a critically important industry and critical technology vulnerability for global governments, and nowhere is that more evident than in Taiwan. For the Taiwanese government, chips are a national security priority, where Taiwan's "silicon shield" has been credited with decreasing the risk of a military confrontation in the Taiwan Strait. As extreme weather events become more frequent and dynamic, so too do the known and unknown consequences of climate change. In order for Taiwan to maintain its leading role manufacturing the world's most advanced chip products, climate resilience and sustainable manufacturing practices will require collaboration and leadership from the public and private sector. As drought conditions are predicted to occur more frequently in Taiwan as a result of climate change, the government and chip industry's response to the 2021 drought provides several key strategies that will be instrumental in sustaining business continuity in the face of future extreme weather challenges. Climate resiliency will be a key component to maintaining Taiwan's leading edge in chip manufacturing and insulating the nation's silicon shield.

Public and Private Collaboration

During the 2021 drought, the Taiwanese government, led by the Ministry Economic Affairs and Water Conservancy Administration, was instrumental in allocating water supplies to Taiwan's Hsinchu Science Park, Taichung Science Park and the Southern Taiwan Science Park.[cvi] Government officials utilized cloud seeding techniques in the atmosphere above its Shihmen water reservoir and built pipelines connecting the city of Hsinchu, home of TSMC, to the water resources in the northern areas of the country. In urban areas, local government authorities instituted water conservation and rationing efforts in Chiayi, Hsinchu, Miaoli, Taichung and Tainan.[cvii] And in some of the most drastic measures, Taiwan's Drought Response Center diverted water resources away from approximately 180,000 acres of agricultural farmland by incentivizing and paying farmers not to grow crops on their land.

As the adverse effects of extreme weather increase business risks throughout the global supply chain, the public and private will need to rely on collaboration and communication on both the local and national level. Chip business leaders will need to consistently communicate their estimated water needs to government officials so that adequate planning and reserves can be allocated. Taiwanese government officials were instrumental in enforcing water rationing measures on the local level, and diverting water supplies on the national level to meet the needs of its citizens and businesses. Taiwan's chip industry leaders must continue to engage with government authorities through trade/business associations, public/private sector events and conferences, and regular consultations between business and government leaders at the highest levels as extreme weather creates new and untested business and national security risks.

Diversification of water resources

During times of drought, governments are forced to choose between supplying its limited water resources to businesses and residents, oftentimes leaving both unsatisfied. The 2021 Taiwan drought was no different. In the midst of supply chain disruptions during the height of the COVID-19 pandemic, Taiwan's drought conditions forced businesses and government to rethink how water resources were allocated, transported and created. Micron Technology secured alternative water supplies for one of its dynamic random-access memory (DRAM) facilities in Taichung and Taoyuan, while TSMC diversified its water resources by having water transported by truck directly to the company's fabrication buildings in Hsinchu. In April 2021, the Ministry of Economic Affairs announced plans to build desalination plants in Chiayi, Hsinchu, Tainan, and Taoyuan that are estimated to produce up to 1 billion cubic meters of water per year by 2031. The government also constructed a water pipeline from Hsinchu to Taoyuan, a city north of Hsinchu that gets more precipitation.

Sustainable manufacturing practices and Better Water Resource Management

Increasingly frequent droughts are forcing the chip industry to explore and invest in water conservation technology. In 2022, TSMC built the world's first industrial waste-water recycling plant used for advanced chip products in Tainan's Southern Taiwan Science Park.[cviii] In conjunction with the Taiwanese engineering company China Technical Consultants Incorporated (CTCI), TSMC has invested in processes using innovative green technologies by recycling industrial wastewater in the chip-making process utilizing reverse osmosis technologies, advanced ultra-filters, and multiple bio-treatment processes to provide ultra-pure water that chip facilities rely on. TSMC expects its water recycling plant to eventually meet up to half of the company's domestic water consumption.[cix] In United Microelectronics Corporation's

2022 Sustainability Report, the company introduced its "Low-Carbon Supply Chain Initiative" by investing 100 million Taiwanese dollars (3.2 million U.S. dollars at current exchange rates) to reduce the carbon footprint of businesses in its supply chain.[cx] In December 2022, Vanguard International Semiconductor Corporation (VIS) became Taiwan's first chip company to join the RE100 -- a global initiative where businesses commit to renewable electricity for 100% of its global operations – and plans to achieve net zero carbon emissions by 2040.[cxi] Chip companies are also increasingly examining the impact of their water needs in environmental impact assessments of new facilities.

In light of all of these efforts, the public and private sectors are still learning how to adapt to less rainfall to prevent catastrophic water shortages that could be detrimental to the global semiconductor supply chain.[cxii] [cxiii] [cxiv]

Outlook

The drought event in Taiwan resulted in water allocation being threatened for both critical manufacturing and for the communities across the island. This type of incident has repeated in other major manufacturing hubs like China and the United States as worsening weather events impact critical resources and subsequently international supply chains.

The United States has now sustained 348 weather and climate disasters since 1980 where overall damages/costs reached or exceeded $1 billion with the total cost exceeding $2.510 trillion.[cxv] Major weather events moving across multiple regions can cause disruptions to transportation, energy supply, supply chain movements, critical personnel, and physical damage to the sites and resource hubs. These hubs can be impacted by extreme weather events such as torrential flooding, extreme heat, wildfires, tropical cyclones, severe storms, sea level rise, flash drought, or extreme cold which can destroy the resource or its access points with secondary events like high air pollution days causing significant impacts to key personnel.

In Taiwan, the chip hub Taichung was competing with locals for water use during a prolonged drought resulting in a global chip shortage as operations were reduced.[cxvi] Many international chip companies have plants in Sichuan, including Texas Instruments, Intel, Onsemi, and Foxconn. Chinese lithium battery giant Contemporary Amperex Technology Co. Limited (CATL), which supplies batteries to Tesla, also has a factory in the region. During the 2022 heat wave in the People's Republic of China (PRC), officials from the manufacturing hub of Chongqing notified factories that mandated power cuts in the municipality were extended until further notice, affecting both PC and Apple suppliers. Relocation was widely communicated.[cxvii]

Supply and demand impacts from extreme weather shifts can span from data services to microchips to metals and minerals, all of which play a critical role in facility operations and supporting infrastructure. Goods and services during multinational weather events can also become strained as countries report similar needs for recovery resources like generators, clean water, medications, fiber/power lines, or fire-fighting equipment. Some products, such as wood for construction, see fluctuating prices during disaster events as sudden influxes in demand occur while some events like wildfires and drought can impact lumber provisions as a resource.

Consequences of Inaction

Quick Summary: During amplified weather disasters such as flash drought and extreme heat, impacts to U.S. interests will be evident through a lack of resources, burnout among emergency personnel, prolonged power outages, loss of cooling water for industry, loss of surface water for agricultural sustainability, greater bacteria spread, and threats to societal well-being. Cascading impacts on a climatological scale will include greater precipitation in a shorter duration, more severe storm cells, stronger surface winds, and potentially larger, heavier hailstones.

Weather events are worsening in regards to events a region typically experiences but is now occurring more frequently or with greater intensity, or events developing in regions outside of seasonal norms, or the start of record-breaking events across multiple areas.

A failure to mitigate impacts from worsening weather events and cascading impacts will result in global market shifts, industry delays, and greater costs to repair during a time when multiple states, regions, or countries could be facing recovery simultaneously.

During onset of and recovery from extreme weather events, communities face unrest regarding resource allocations such as water theft during times of drought in California and Oregon, and authorities with uncertainty regarding a return to normalcy such as in Florida and Louisiana.

Facing the chip shortage in the United States resulting in delays for automobiles, computer parts, and even home appliances while reducing the push towards particular innovative technologies reliant upon microchips. Other key resources at similar risk include coal, lithium, copper, whiskey, beer, not to mention recent policy shifts to move away from harmful substances like PFAS to prevent further ecological damages which impacts numerous goods globally.

Shifts away from the climatological norm can impact populations of a site's key workforce and can cause prolonged damages to operations and sustainability in the region moving forward. Implementing a resiliency measure due to one disaster can result in new or unforeseen impacts which should be provided as caveats, such as installing a large solar field resulting in a localized heat field and subsequent increase in local temperatures which could worsen storm events; or installing new infrastructure requiring greater energy needs in regions with recent record breaking temperature events which may cause current infrastructure to fail.

According to research conducted by Verdantix, "more than half of organizations have less than $1 million to respond to catastrophic events, and 41% of participants stated that they had no budget at all for catastrophic events."[cxviii]

- The report found that "over two-thirds of organizations had a loss caused by an extreme weather event in the two last years, with most submitting an insurance claim for these events".

According to the Harvard Business Review: 80% of all sites in the United States and 48% of all sites in China and Taiwan have either no business continuity plans or no alternative sites lined up that could be put into operation quickly; in other words, they are unprepared for disruptions to their operations.

- Of the high-revenue-at-risk sites, 72% of those in the United States and just 38% of those in China and Taiwan lack these formal measures.[cxix]

MITIGATION OPTIONS AND BEST PRACTICES

Examples of Mitigation Options and Associated Examples

Extreme Heat

Cities across the world are adding green roofs to buildings in a bid to both increase biodiversity and negate the impacts of extreme heat. According to the U.S. General Services Administration, green roofs can make the associated roof surface 30-40% cooler and reduce the fluctuation in the roof from heat up to 72%.[cxx] These planted surfaces also become home to local wildlife and in some cases support farms providing produce to local restaurants. Chicago is leading the way in green roofing efforts in the United States, with over 500 green roofs amounting to 5.5 million square feet of coverage as of 2022. For a large city like Chicago, the green roofs can help tamper down on the heat island effect felt by large cities during periods of extreme heat.[cxxi]

Extreme Cold

Given the sudden implications of a winter storm, preparations in the longer term may seem less viable given the climate studies indicating after 70 years the threat margin from these events shrinks notable, there are many opportunities to prevent significant damages through that period. Frozen electrical equipment such as transformers, renewables like windmills and solar panels, and fuel pipelines can result in an inability to meet energy demands. Site owners and operators could install an electric heating for wind turbine systems like those used in the areas exposed to harsh winter weather events historically which operate windmills.

Additional practices include increasing anti-freeze applications to motors/turbines, provide easier access to rapid use covers, and increase automated temperature sensors to track onset of temperature shifts. Sites should always be looking to compare energy infrastructure to more resilient states to strengthen their equipment. Winterizing fuel is also an often-overlooked part of the season in some southern states which can lead to cascading failures.

Larger Wildfires

While some wildfires are good for natural removal of undergrowth and can help remove non-natives plants from a regional and reduce the insect population, the emissions from wildfire burns are unsustainable given the amplified of heat, pollution, and water vapor in the atmosphere due to human activities. Larger wildfires which move through populated areas can cause significant damage to unprotected infrastructure. Concrete can begin cracking at 500 degrees Fahrenheit, suffers large cracks at 1,000 degrees, and melts at 2,500 degrees depending on the concrete class mix. Thereby it is recommended that teams install fire blankets under critical bridges and around support systems to improve resiliency from exposure to flames of 3,000 degrees or more when an area is flagged for wildfire activity. Cities and towns could also develop recycled water sprinkler towers to slow fires approaching sites/towns.

Prolonged Drought

Drought as a slow onset problem for the long term with an extreme side within the flash drought development has a slew of opportunities to reduce impacts and improve resiliency available. A key one, blackwater recycling, can provide a seemingly closed-loop water system with residential sites, communities, or even critical infrastructure sites which would remove the core dependency on city water. Given disasters are becoming larger and more intense, larger scale power outages and infrastructure damage are likely, presenting a need to shift towards community resilience hubs instead of cityscapes. Greywater systems reduce indoor water consumption by as much as 25% and a family of four can reduce water use by 20,000-40,000 gallons annually. Shifting critical sites to blackwater recycled water systems has proven that industrial sized buildings can improve to near 93-99% water use efficiency. The beverage industry (Coca-Cola and various beer companies) has already shifted their sites to blackwater recycling to prevent extended down time during heat waves or floods in the future.

Sea Level Rise

Coastal flooding leads to destructive agricultural erosion and soil contamination in non-saline habitats which negatively impacts fish, birds, and plants native to the area. Mitigations focused on construct underwater sill barriers to prevent saltwater inflows to river systems and moving towards natural resiliency have proven the most effective at long-term sustainability. Utilizing Natural Infrastructure like mangroves, wetlands, reefs, and sand dunes where living shorelines are possible to reduce inflow threats can last longer in many areas than placing non-typical materials like cement barriers to the same effect. Oyster reefs and marshes act as natural barriers to waves and 15 feet of marsh can absorb up to 50% of incoming wave energy according to NOAA.

Severe Storms

Certain industries throughout the United States already know of resiliency methods against severe storms, such as deployable flood barriers and debris removal systems, although the real solution lies in prevent the impact to the residential communities and infrastructure. Knowing that certain home styles, bridge layouts, mountain passes can see impacts from the supercells moving through the area, preparation for these events requires systematic change or re-zoning. Changing the building market is likely easier than refused to establish homes for an expanding population overall. From 2010 through 2020, tornadoes resulted in $2.5 million in property damage per storm. One method of mitigation is to expand use of cement domes containing critical components to improve aerodynamics against strong winds and reduce damage from debris. Using steel reinforced, insulated concrete forms which can withstand winds of over 200 mph and integrating the robust Monolithic Domes can withstand winds from a EF5 tornado with minimal material cost.

Torrential Flooding

Given that deployable flood barriers often fall to individuals to own and operate in a rapidly unfolding crisis event, a more preemptive resiliency measure is to address the absorption rate of the falling water at the surface which prevents total accumulation from becoming overwhelming. Stormwaters can overflow canals and amplify embankment erosion rates, deposit sediment, decreased water retention, and can bring harmful material into wells, across farmlands, and throughout local reservoirs. To prevent this, communities can increase the height of canal walls can reduce overspilling rates and lining the canals can reduce erosion threats, install native plants along canal edges to filter pollutants entering the canal and reduce total inflow rates during floods, cover the canals to slow stormwater inflow rates, reduce debris flows entering the water system, and act as a lid for overflowing waterways moving through the canal, and even install river and well monitoring can reduce exposure to harmful pollutants and gauge water level rates and increase groundwater storage entry points/funnels.

Tropical Cyclones

Given that tropical cyclones produce multiple events which are in themselves extreme weather events, the resiliency methods implemented in other categories will have cascading benefits in this regard as well. One topic often left untouched, how to prevent the threats to agriculture, surface waters, and the community capability to respond post even without struggling for food and water. The damage from a tropical weather-based floods can last multiple seasons as the soil health is strongly affected by debris, contaminated water, higher levels of toxins or chloride, or by stripping nutrient filled topsoil. Communities can plant cover crops in rural areas and along flowerbeds in cityscapes to improve soil resiliency to a flash flooding and can provide natural water filtration to reduce aerosols entering farmland. The communities along major water ways can reduce toxic algal blooms with aeration devices in local water ways post-landfall and increase presence of natural vegetation to naturally filter toxins.

Observed Best Practices for Public and Private Organizations

Extreme weather events will continue to threaten the United States in the coming years with future trends indicating an uptick in the regularity and severity of these events as the impacts of climate change accelerate. U.S. Government agencies and private sector organizations must adapt to these changing conditions or risk severe damage. The degradation or outright destruction of critical infrastructure and the disruption to supply chains from extreme weather events threatens companies across industries and undermines the U.S. Government's ability to protect the country from a range of threats. However, while public and private sector organizations cannot eliminate the threat of extreme weather, these organizations can pursue mitigating measures to bolster resilience and maintain operations despite a plethora of extreme weather events. Although many of the below listed best practices are already commonplace across some industries like transportation and energy, extreme weather can impact all manner of critical infrastructure sectors as demonstrated by the two case studies in this report. The following best practices apply to a wide range of public and private sector organizations and serve as potential first steps towards building resilient and sustainable organizations in the face of extreme weather threats:

- *Information Sharing:* U.S. Government agencies and various private sector critical infrastructure operators take part in a number of information sharing efforts through Information Sharing and Analysis Organizations (ISAOs). These ISAOs allow U.S. Government agencies to share pertinent threat intelligence, primarily cybersecurity threats, with private sector organizations to help the latter protect their organizations and operations. The private sector participants can share threat indicators they collect and report on attempted attacks on their companies. This bidirectional information sharing helps all entities gain a better understanding of the overall threat environment. Applying a similar model to extreme weather events, working through existing ISAOs or establishing new information sharing pathways between U.S. Government agencies responsible for monitoring and response with companies facing extreme weather threats, could help both entities better understand the dynamic threat environment and jointly prepare. Weather data is not subject to the same level of classification and sensitivity as much of the historic data shared through ISAOs, which allows U.S. Government agencies a freer hand to disseminate warnings and findings to a wider swathe of companies in industries critical to elements of U.S. national security.

- *Risk Assessments:* Extreme weather events will touch companies in every industry and undercut the operations of every U.S. Government agency in some form or fashion either directly or indirectly. The interconnected nature of our society, economy, and national security ensures that impacts felt in one region quickly cascade into others. While it is impossible to eliminate the risks posed by extreme weather events, a risk assessment can help organizations understand mitigation options to reduce risk. A risk assessment identifies potential threats and compares them against existing vulnerabilities to determine the potential consequences an organization will face given the occurrence of the aforementioned threat (in this case, an extreme weather event). Both private and public organizations can benefit from risk assessments which analyze the direct and indirect threats posed by extreme weather events. By conducting a risk assessment, a private company can better understand how the geographic distribution of their assets, personnel, and supply chains could become impacted by extreme weather events and explore options to build redundancy and resilience into operations. Similarly, a U.S. Government agency can better understand what steps are necessary to maintain operations in the face of weather crises and what private sector entities underwrite the agency's ability to perform critical missions. Public and private sector organizations can fully understand the full extent of their interdependence by conducting a comprehensive risk assessment and exploring the proper mitigation steps. The DOD is one of many U.S. Government agencies exploring the challenges posed by extreme weather events by conducting climate risk analyses to identify the nature of extreme weather threats facing the U.S. military's global infrastructure, the existing vulnerabilities, and the potential consequences on the agency's ability to fulfill critical missions.[cxxii]
- *Emphasizing Resilience in Design:* Building infrastructure and organizations with resilience in mind can help public and private sector organizations sustain critical operations even in the face of devastating extreme weather events. Resilience can take many forms. Strengthening physical infrastructure helps agency or company facilities and assets sustain the immediate dangers posed by an extreme weather event and shortens the time to return to normal operations. Distributing critical assets, like energy and communications infrastructure, can help an organization maintain operations even if parts of a network are damaged or knocked offline. Establishing a network of suppliers in diverse localities can help sustain supply chains even if there are isolated disruptions due to extreme weather events in one region. The DOD's reconstruction of Tyndall Air Force Base in

Florida is an example of an agency emphasizing resilience in design. The base suffered severe damage from Hurricane Michael in 2018 and in response, the DOD is designing an airbase capable of withstanding Category 5 hurricanes and associated flooding. The reconstruction will ensure the base can survive a catastrophic storm and quickly return to operations sustaining critical national security missions.[cxxiii]

CONCLUSION

The United States will face increasingly common and more severe instances of extreme weather events in the coming decades. However, the extent of cascading impacts caused by these extreme weather events will depend on how aggressively public and private sector organizations work to build resilience within organizations and infrastructure. There are a variety of mitigation options which can help address the threat posed by any of the eight major identified extreme weather events. Public and private sector organizations can both benefit from reviewing, implementing, and maintaining these mitigation measures. In addition, establishing public-private practices and considering best practices for cooperation can help the United States at large manage the damaging impacts of extreme weather events. These steps can help contain the potential cascading impacts throughout critical infrastructure sectors, international supply chains, and the economy. However, it is critical to note that the impacts of extreme weather are not limited to the United States. In many cases, extreme weather events could limit our ability to project power abroad by degrading or destroying military infrastructure or forcing the reallocation of critical U.S. military assets. Other countries will feel these impacts and not all of them are as well placed to address the fallout of extreme weather events. Mass international migrations, collapsed governments, and ungoverned spaces alongside international supply chain disruptions are real possibilities by 2050 as a direct or indirect result of climate change. The United States is facing a future where climate change and extreme weather events are central to national security considerations. Whether direct or indirect, the United States will continue to feel the impacts and implications of extreme weather events for decades to come.

ANALYTIC DELIVERABLE DISSEMINATION

Teams: Please list entities that would best benefit from receiving this deliverable. The bullets below are an example. Please include your original ideas.

U.S. Department of Transportation

U.S. Department of Agriculture

U.S. Department of Defense

U.S. Department of Health and Human Services

Environmental Protection Agency

U.S. Department of the Interior

Edison Electric Institute

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