

White Paper:

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Preparing for increased weather volatility

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As the population grows and infrastructure expands, increased exposure and vulnerability to these hazards requires risk planning and adaptation for greater resiliency.

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In our previous white paper on climate change and increased weather volatility, we outlined how the climate system can change from both natural and man-made influences. It remains unknown exactly how much humans are impacting the natural evolution of climate through land-use changes and greenhouse gas emissions. Projecting those influences into the future with certainty is not yet possible. Our conclusions are that more actionable courses of planning and preparation can be made based on observations of the more recent volatile or extreme weather events, which have been taking place over the last two decades.

Extreme weather is nothing new. Throughout historical record, there have been many occurrences of extreme weather events. Recently, however, some forms of extreme weather have been happening more frequently than natural variability would suggest. It is not known if this volatility will continue into the future, or if this active trend will return to more normal frequencies. Recent research suggests this volatility could be a result of the enhanced warming that has taken place in the Arctic region.² A reduction in the temperature contrast between the Arctic and the middle latitudes could be weakening the jet stream, causing the resulting atmospheric circulation pattern to buckle and stall out more often. The observed extreme weather events tend to occur more frequently when the jet stream remains stalled in these buckled or wavy configurations for longer periods of time. When weather patterns stall, flooding is more likely to occur as moisture can pool and support repetitive, heavy rains that fall over the same local areas. Wetter or drier-than-normal periods can develop when air masses do not move from a given area. Abnormally cold or warm periods can linger for months, as the jet stream stays locked into the same position for extended periods with little variation. Severe weather will be more common in some of these stalled patterns, and less likely in others. For whatever the cause, the stalled, wavier jet stream behavior leads to more incidents of extreme weather.

Increased exposure and vulnerability

In conjunction with a more volatile weather and climate system, it is important to consider how society is changing as well. Currently, 80 percent of the U.S. population lives in urban areas with high population densities, and demographic trends suggest that urbanization will continue to increase in the future.

This means that urban, along with rural-metro areas, are expanding into a larger portion of the landscape, while rural areas with low population density are shrinking. Cities will continue to drive economic growth and wealth, while at the same time concentrating vital infrastructure within highly local areas. Infrastructure elements that are focused within cities include energy, water, wastewater, transportation, public health, banking and finance, telecommunications, food, and information technology. Impacts from a more volatile climate system can therefore have more substantial effects when they occur in these centralized urban areas. Flooding can damage or wash away homes, businesses, and infrastructure, affecting jobs and vital services. At the same time natural flood management is constrained as urbanization reduces the area available for holding floodwaters. Extreme heat, which tends to be more intense in urban cores, can compromise health – especially with an aging population. It can also reduce productivity and impact the functionality of infrastructure. Dry spells, especially ones leading to drought, produce water scarcity issues as cities compete with agriculture, energy production, and recreation for limited water supplies.

Slower, wavier jet stream



Strong polar vortex: faster jet stream winds

Figure 1 Wavier jet stream.



Weak polar vortex: slower winds, more waves





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Figure 2 shows the current geographic coverage of the expanding urban and metro areas, putting more types of infrastructure into the path of potential weather hazards.³ Census-defined urban acreage has grown by about four percent per year since 1960, or roughly a million acres per year.⁴ Rare weather events, such as an EF5 tornado or an extreme flood, will have an increased probability in the future of intersecting with larger population



Figure 2 Urban and rural-metro areas.

centers, based on urban growth trends alone. Exposure and vulnerability are key factors when evaluating risk. A tropical cyclone can have very different impacts depending on where it makes landfall. High impacts can result even when a non-extreme event occurs where exposure and vulnerability are high, or where several significant events compound problems.

Costs of natural hazards

The Hazards & Vulnerability Research Institute routinely examines county-level hazard data for 18 different natural hazards in the United States, including costs and fatalities that are attributed to these hazards.⁵

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3. USDA, 2013. Rural Classifications. http://www.ers.usda.gov/topics/rural-economy-population/ruralclassifications/what-is-rural.aspx 4. USDA, Trends in Land Use: Two Kinds of Growth. Development at the Urban Fringe and Beyond/AER-803. http://www.ers.usda.gov/media/536705/aer803c_1_.pdf

5. Hazards & Vulnerability Research Institute. 1960-2015 U.S. Hazard Losses. http://hvri.geog.sc.edu/ SHELDUS/docs/Summary_1960_2015.pdf Recently, some forms of extreme weather have been happening more frequently than natural variability would suggest. It is not known if this volatility will continue into the future, or if this active trend will return to more normal frequencies.

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Figure 3 shows the breakdown of the monetary and human losses for each hazard type during the 56-year period from 1960-2015. Hurricanes and tropical storms have been the most costly type of natural hazards during this period, accounting for 31 percent of the reported losses. Flooding came in second with 20 percent. It is noteworthy that these two hazards, which account for 51 percent of all losses, are related to water, highlighting the significance that water plays in natural disaster costs. Fatalities are more dispersed among the hazards with less focus on the water impacts, and more on severe weather.

Annual losses from natural disasters can vary from year to year. Figure 4 depicts a plot of the costs from 1960-2015 in 2015 dollars. There has been an upward trend in weatherrelated losses over the past 20 years. This is likely a combined influence of more active extreme weather, the increased growth and exposure of society, and the increased value of property. Several outlier years show up in this graph, including 1994, which experienced the Northridge earthquake in southern California. In 2004 and 2005, two back-toback active tropical seasons, there were seven major hurricanes (Category 3 or greater) that made landfalls in the United States, including Hurricane Katrina. Even though Superstorm Sandy was not a major hurricane at landfall it still accounted for the high losses in 2012. It was not until 2017 that Major Hurricane Harvey made landfall in the U.S. ending a nearly 12 year streak of no major storms making a direct hit on the U.S. mainland.

In the past decade there has been a noticeable increase in the number of higher-cost disasters in the United States. Starting in 2008, there have been greater occurrences of billion-dollar events, primarily from severe thunderstorms. Both 2008 and 2011 were very active tornado years. Several destructive storms passed through sizeable metropolitan areas, resulting in widespread, heavy damage. There were also several larger-scale windstorm events that generated long-tracked paths of damage through highly-populated areas. Figure 5 illustrates this more active recent period of high-cost storms.⁶

Extreme weather events and impacts

Considering both the background on historical weather- related costs and the continual growth in population centers and associated infrastructure, it is useful to examine which weather hazards have increased or are more likely to continue to show an increase, due to recent climate and weather volatility. While the most extreme events remain locally rare in nature, it is helpful to explore some of the more common volatile weather events and the impacts that are more likely be encountered, so that actions to limit their disruptions can be evaluated and implemented.







Figure 4 Annual U.S. hazard losses (1960-2015).



Figure 5 Billion-dollar disasters by type.



Excessive rainfall and flooding

One of the most noticeable weather events that has shown an increase in recent decades is the greater frequency of extreme rainfall occurrences. Flood losses in the United States have accounted for around 20 percent of natural hazard costs since 1960, and this amount could increase in the future if recent trends hold. Heavy one-day (or multi-day) rainfall events have shown a greater frequency in the past two decades, especially in the warm season, as shown in Figure 6.⁷ The graph represents the annual percentage of the United States that experienced one-day precipitation amounts in the top ten percent of historical occurrences. Intense rainfall rates contribute to rapid run-off and flooding, especially in urban areas, where impervious surfaces have expanded in size.

Individuals, businesses, and communities should evaluate the risks associated with extreme rainfall events and consider the impacts that typically occur during and after such incidents. Efforts should be made to identify local areas prone to flooding when excessive amounts of rain fall. Some of the more commonly observed flood risk scenarios and local impacts include:

Flash floods — extreme rainfall rates with rapid accumulation and runoff. Storm water cannot be removed fast enough to prevent flooded areas. Greater impact occurs with alreadysaturated soils.

New development in urban areas — more runoff occurs from roofs and pavement; less ground is available for absorption due to the building of structures and increased filling of wetlands. Dam/levee failures — there are 74,000 dams in the United States with one-third posing a risk to life and property if they fail. Excessive rainfall, both short-term and over many days, can lead to breaches.

Mudslides, rock, and debris flows — hillsides become unstable when they are saturated by heavy rainfall. Removal of vegetation nearby may contribute to greater soil saturation. Burn scars are more susceptible. See images in Figure 7.)



Figure 6 Climate extremes index for one-day heavy precipitation totals during the warm season.



Figure 7 Mudslide and road washouts from heavy rainfall events in Minnesota (June 2014).





Tropical storms and hurricanes — extensive, heavy rainfall over one to three days can saturate the soil over a large area. Extreme rainfall rates occur near the center of tropical systems, with slow-moving storms capable of prolific flooding as experienced with Hurricane Harvey in Texas in 2017. Storm surges near the coast have the most destructive impact as a tropical storm or hurricane moves onshore.

River and lake flooding — heavy rainfall over a period of time raises lake and river levels, with water expanding onto shorelines and into floodplains. This type of flooding may also occur with ice jams.

Heavy rain on frozen ground or melting snowpack — frozen ground does not absorb melting snow or falling rain, leading to flash flooding, as well as river and stream floods. Heavy rainfall during this scenario produces greater flood risks during the cold season.

Extended periods of abnormal temperatures

It is not unusual for the weather to be colder or warmer than average for short periods of time (days to weeks). Indeed, it is this variation that is averaged over time to define what is normal for a given area. In recent years, there has been a greater tendency for abnormally warm or cold periods to set up in an area and persist for long durations of time (months to seasons). It is the frequency and persistence of these long-duration events that has become more common recently. At times, the intensity of the warmth or coldness itself during a persistent event can become more extreme. These anomalous temperature patterns tend to develop when the jet stream buckles and stalls, keeping coldness or warmth locked into areas for extended periods of time. A recent example of an extended period was the winter of 2013-2014, when cold air remained anchored in the Central and Eastern United States. Temperatures were more than eight degrees colder than normal during January through March 2014 (Figure 8), which is quite extreme for a 90-day period. Europe, Asia, and North America have seen numerous examples of such patterns, both cold and warm, in the last decade. More are likely to occur as long as the slower, more undulating jet stream persists. Energy demands increase during these events, raising costs and stretching energy supplies. Retail sales, especially auto, restaurants, and entertainment venues are hurt as consumers stay at home more often. Home construction can be delayed during extreme cold. Logistical and travel networks can be disrupted, especially when wintry precipitation covers wider areas, resulting in more canceled flights and delayed deliveries.

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Drought, water supply, and wildfires

Drought has resulted in significant longterm economic costs to society. In the United States, there have been a growing number of billion-dollar droughts over the last 30 years, with extreme droughts in the Southeast, the Southern Plains, the Midwest, and California over the past decade. Drought is a natural part of the climate system, varying in intensity, duration, size, and location from year to year. It is common that some portion of the United States will experience drought each year, with a long-term average of 14 percent of the country being impacted annually.

Figure 9 is a timeline depicting what percentage of the United States was in drought each year from 1895 through 2010. Massive droughts occurred in the 1930s and 1950s, with vast areas involved. In much the same way as abnormal temperature patterns set up with stalled and wavier jet stream patterns, droughts develop when the jet stream steers around a region for many months, decreasing the chances for precipitation. Droughts are slowly developing disasters that can expand outward with time and encompass more territory. Irrigation and the planting of more drought-tolerant crops help to lessen the impacts of drought. Crop losses can result in shortages that push up food prices and sometimes lead to the culling of livestock herds by ranchers as water and feed supplies are reduced.

NOAA/NCDC Climate Division Temperature Anomalies (F°) Jan to Mar 2014 Versus 1981-2010 Longterm Average



Figure 6 Climate extremes index for one-day heavy precipitation totals during the warm season.



Based on data from the National Climatic Data Center/NOAA

Figure 7 Mudslide and road washouts from heavy rainfall events in Minnesota (June 2014).

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Drought is likely to be a significant threat in the future, even in the absence of any upward trends in intensity and coverage. Rainfall deficits over a long period of time put strain on available water resources. Growth in water usage will escalate as the population increases and new water utilizations, such as hydraulic fracturing, increase demands. Figure 10 shows the trends in surface- water, groundwater, and total-water withdrawals for the United States from 1950 to 2010.⁸ The relative amounts of surface and groundwater withdrawals have remained fairly constant since 1985, even though the population has grown, along with irrigation and industrial growth. This slow-down in use is likely due to water conservation practices and efficiencies put in place since that time. About threefourths of the water used in the United States comes from surface water.

Figure 11 allocates the primary users of the water supply. Water use for electricity production, the largest user, increased almost 500 percent from 1950 to 1980, but has leveled off and even decreased since then. Irrigation use increased by about 43 percent as it takes more water to grow food for an increased population and global markets, but it too has been reduced in recent years. The purple public-supply boxes, which represent local water supplies delivered to homes and businesses, has shown steady slow growth and may grow further due to ever- increasing population demands.

Abnormally dry weather patterns and droughts can have a greater impact when they occur in areas where the water supply is more limited. Figure 12 illustrates the concept of a water supply stress index. The index shows areas where watersheds are considered stressed when water demand from power plants, agriculture, and municipalities exceed available supplies.⁹

An index value of 0.4 (40 percent) or greater is considered stressed. In addition to much of the arid West, a number of local or regionally stressed areas are also found in the eastern part of the United States. California and the inter-mountain western







Figure 11 Water withdrawals by category.



Figure 12 Water stress index (figure source: Averyt et al. 201120).



 USGS, 2010. Trends in Water Use in the United States, 1950 to 2010. water.usgs.gov/ watuse/wutrends.html
UCS, 2011. Freshwater Use by U.S. Power Plants. http://www.ucsusa.org/assets/ documents/clean_energy/ew3/ew3-freshwater-use-by-us-power-plants.pdf



United States get most of their annual rainfall during the winter months, so an extreme drought of just three to four months duration can have an enormous impact. Drought in the future will put added strain on water resources, requiring greater sharing and coordination among various consumers, especially in areas of more limited supply.

Extreme dryness or drought can also lead to enhanced wildfire conditions. Wildfires have always been a part of nature, with a tendency to be more common during the hot and dry season. Lightning initiates many fires in the more arid western United States, but humans are a contributor as well, whether by accident or arson. Wildfire activity in the western United States increased substantially in the late 20th century with the increase primarily caused by higher temperatures and earlier snowmelt. Similarly, increases in wildfire activity in Alaska from 1950 to 2003 have been linked to increased temperatures. The principal economic costs of wildfires include timber losses, property destruction, fire suppression efforts, and losses to the tourism sector. Encroachment of urban development into areas that are susceptible to wildfires increases the risks



Figure 13 Average annual number of structures destroyed by wildfire inthe U.S.

and costs when fires break out. Figure 13 depicts how fire losses in California have increased significantly in recent decades, as the urban-wildland interface increased from greater development. Over five million homes in California are located within the urban- wildland interface.¹⁰ Vulnerabilities for landslides increase in areas with thinned vegetation from droughts or wildfires.¹¹

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Managing risks

Disaster risk planning and management, in light of recent weather and climate volatility, are sound practices to help prepare for and reduce costs associated with the increased hazard threats. Recent changes in these threats might result in new vulnerabilities that were not previously encountered or understood. Many of the more acute weather events are unpredictable and unevenly distributed across space and time, so knowledge of exactly when and where they might occur is limited. Increasing resilience to these changing risks can be accomplished by reducing exposure, lessening vulnerability, or transferring or sharing the risks through insurance. Risk management is often governed by the probability of an event multiplied by its consequence. For example, an EF5 tornado is a rare event, but one that moves through a metropolitan area can have devastating results. Reducing exposure and vulnerability to these events reduces the risk, but may come with great cost or political resistance. Risk transfer is a method of insuring against potential losses, which may be a more economical way to guard against a lowprobability occurrence.

Various business sectors and local populations have begun to document their experiences with the changing climate system, particularly with extreme weather events.¹² Some of this self-generated knowledge may help facilitate discussions on proactive adaptation strategies. It might also help discover some existing capacity to adapt or it may reveal important current shortcomings. Some of this information on best practices can aid the development of vulnerability and adaptation assessments. The following section highlights a number of the observed and expected impacts on several sectors of business and infrastructure, along with suggested methods for adapting to the risks.

Energy

Sector-based impacts and practices for increasing resilience

Energy - recent climate volatility has raised the awareness of its impacts on the energy industry. Severe droughts, such as those seen in 2010, 2012, and 2014, can affect the supply of cooling water to power plants, disrupting the supply of power.¹³ Abnormal and persistent temperature regimes can strain fuel supplies and impact earnings. Flooding of infrastructure, especially along coastal areas, can take those facilities offline, as well as require costly repairs. Insurers have recently started to factor in climate change in their insurance cost calculations. Insurance affordability and availability could potentially slow the growth of the energy industry and shift more of the costs to users.

More extreme rainfall:

- Flooding of infrastructure, especially near waterways and floodplains can take those facilities offline, as well as require costly repairs.
 - Harden plants and substations to reduce the threat of flooding in susceptible areas to help decrease this risk
 - Elevate platforms used to store materials
 - Preserve and improve open space in floodplains
 - Utilize short-term weather forecasts
 - Install weather stations to monitor events in real- time
- Higher volumes of precipitation can saturate soils and weaken support for electric distribution poles, making them less study during strong winds.
 - Inspect distribution infrastructure
 - Examine areas where mudslides or erosion could occur

10. Environmental Research Letters, 2009. Urban-wildland fires: How California and other regions of the US can learn from Australia. http://cnr.berkeley.edu/ stephens-lab/Publications/ Stephens%20et%20al.%202009%20C4%20AU%20UW%20En%20Res%20Let.pdf 11. USDA, 2012. Effects of Climatic Variability and Change on Forest Ecosystems. http://www. usda.gov/cce/climate_change/effects_2012/FS_Climate1114%20opt.pdf 12. CDP, 2014. Major public companies describe climate-related risks and costs. https://www.cdp.net/CDPResults/ review=2011-2013-USA-disclosures.pdf 13. Pulwarty, R.S. 2013, Testimony of Dr. Roger S. Pulwarty on Drought and the Effect on Energy and Water Management Decisions, U.S. Senate Committee on Energy and Natural Resources. http://www.legislative.noaa.gov/Testimony/ Pulwarty042513,pdf





Extended periods of abnormal warmth or cold:

- Extreme cold can stress energy supplies and infrastructure. Conversely, earnings can be affected significantly during the winter heating season if weather is abnormally warm and energy usage is reduced. An increase in extreme heat will drive up demand for air conditioning, requiring greater electric loads and peak generating capacity.
 - Use a longer historical record (such as the past 100 or more years) for estimating extreme or peak values
 - Utilize longer-term seasonal weather forecasts
 - Insulate equipment for temperature extremes
- More extreme temperature patterns could increase the threat for stronger coastal storms that produce high winds and waves. These may curtail coastal and offshore oil and gas production, temporarily driving up prices and producing shortages. Coastal storm surges could also flood vulnerable infrastructure.
 - Upgrade flood protection
 - Use weather consultations for pre-storm planning

Extreme dryness or drought:

 Drought, especially severe droughts, reduces the supply of cooling water to power plants and increases costs for water-use rights and permitting. Reduced hydroelectric power resources require shifting to more expensive power sources.

- Bank water in reservoirs during offpeak seasons
- Use seasonal weather outlooks and consultations for planning
- Water usage, which will continue to grow with an expanding population, will strain existing resources in the future with increased competition among sectors. Drought in water-stressed areas could curtail hydraulic fracturing operations.
 - May need to rely on more expensive groundwater sources
- In areas with increased wildfire risks, overhead power lines and substations can be damaged when a fire moves through.
 - Forest management (thin and remove debris near streams)

Transportation

Transportation — transportation infrastructure is especially vulnerable to precipitation extremes. Flooding produces a significant impact on infrastructure, including high water that occurs with flash floods, river and stream flooding, and storm surges. Floods can damage infrastructure, including roads, bridges, culverts, and even railways, airports, and coastal ports. Rushing water can wash out soil that surrounds bridge foundations, weakening the support function. Mudslides occur when heavy rain destabilizes hillsides, which can quickly close roads or cut-off communities. Road washouts, mudslides, and

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flooded roads can delay deliveries and inhibit employees' ability to commute to workplaces. River flooding that follows heavy rain events or low water levels during drought conditions, can restrict river transportation, disrupting barge traffic. Flash floods can be costly to rail transportation, which is primarily impacted by bridge washouts.

Extreme temperatures can also impact transportation infrastructure. They cause expansion and increased movement of concrete joints, protective cladding, coatings, and sealants on bridges and airport infrastructure, and stress the steel in bridges. Extreme heat along with rapid temperature changes can damage rail tracks as the track buckles.¹⁴

The following list includes some ways that the transportation sector is assessing increased weather risks with methods to help manage those concerns:

More extreme rainfall:

- Flooding of infrastructure includes roadway flooding, damage or destruction to bridges, pavement washouts, mudslides, subway flooding, airport flooding, and curtailment of barge operations.
 - Upgrade drainage facilities and capacity for more extreme rainfall events. Consider 100-500-year rainfall risks.
 - Protect existing infrastructure, such as bridge foundations from floodwaters
 - Preserve and improve open space in floodplains
 - Reinforce slopes
 - ° Relocate vulnerable routes
 - Increase inspections and maintenance of levee and drainage systems, including riverbeds
 - Enhance emergency response to flooding
 - Install weather stations and early warning systems to monitor events and assets

Extended periods of abnormal warmth or cold:

- Extreme heat can cause rail tracks to buckle and kink, disrupting rail service until the track is replaced. High temperatures can cause concrete pavement to buckle or explode, especially when recent rainfall has seeped into its cracks.
 - Increase inspection of track during high heat and large temperature swings

Extreme dryness or drought:

- Severe droughts reduce the water flow on inland water systems, which can disrupt barge traffic.
 - Shift product shipments to train and truck delivery
 - Use seasonal weather outlooks and consultations for planning

Municipalities

Municipalities — the United States is highly urbanized with approximately 80 percent of the population living in metropolitan areas. Aging and concentrated infrastructure in these urban areas is at an increasingly higher risk from extreme weather events. Examples of urban infrastructure elements that are at risk include energy, water, wastewater, transportation, public health, banking and finance, telecommunication, food, and information technology. Disruptions in essential services can have large impacts because many of these services are reliant upon each other.

High impact events for municipalities include, extreme rainfall leading to flooding, storm surge flooding in coastal locations, severe storms that cause property damage and power outages, snow and ice storms that snarl transportation and trigger power outages, periods of extended dryness leading to water shortages, and high heat and humidity leading to health issues. Drought increases fire risks in the urban-wildland interface.



Land management is an important tool to help offset some impacts, especially flooding. This includes land use planning, zoning, conservation zones, buffer zones, or land acquisition. Often it is difficult for local jurisdictions to implement such management measures due to political and economic pressures for new development, or the perception of shifting the problems onto others.¹⁵

Heavy precipitation events are strongly correlated with the outbreak of waterborne illnesses in the United States, primarily from water supply contamination and sewage treatment plant overflows. Fifty-one percent of waterborne disease outbreaks were preceded by an extreme precipitation event.

The following list includes some ways that municipalities are assessing the increased weather risks with methods to manage those concerns:

More extreme rainfall:

- Flooding of infrastructure includes roadway flooding, damage or destruction to bridges, pavement washouts, mudslides, and subway and airport flooding. Sanitary sewer backups occur when storm water overwhelms that system.
 - Upgrade storm water drainage facilities and capacity. Consider 100-500-year rainfall risks.
 - Reduce infiltration of rainwater into the sanitary sewer system
 - Protect existing infrastructure, such as bridge foundations, from floodwaters
 - Preserve and improve open space in floodplains through land-use planning and zoning
 - ° Create conservation or buffer zones
 - Reinforce slopes
 - ° Relocation of vulnerable routes
 - Construct or enhance levees in areas at risk from storm surges
 - Increase inspections and maintenance of levee and drainage systems, including streams and riverbeds

- Enhance emergency response to flooding
- Monitor the water supply for disease potential
- Install weather stations and early warning systems to monitor events and assets

Extended periods of abnormal warmth or cold:

- Extreme cold or heat can stress the urban population. The elderly are particularly sensitive to heat waves. Some may be physically frail, have limited financial resources, and/or live in relative isolation in their apartments. They may not have adequate cooling (or heating), or may be unable to temporarily relocate to cooling stations. Extended periods of heat can be focused in cities, which often retain more heat at night.
 - Develop plans for public health and welfare during heat waves, including cooling centers

Extreme dryness or drought:

- Severe droughts reduce the amount of available water supply to cities, and increase demand for watering and recreation.
 - Proactively institute water restrictions
 - Use low-water landscape techniques

Agriculture

Agriculture — agriculture experiences a number of the impacts from a more volatile weather and climate system. Farmers have been on the front lines of these changes and have taken measures to help offset their risk. Commodities that are produced by this industry will be vulnerable to direct impacts, such as changes in crop and livestock development and yield, as well as indirect impacts from pests and pathogens that emerge in some volatile patterns.



The following list includes some ways that the agriculture industry is assessing the increased weather risks with methods to better manage those concerns:

More extreme rainfall:

- Flooding extreme rainfall, beyond the direct destruction of property, has important negative impacts on agriculture. Heavy precipitation and field flooding of agricultural systems delays spring planting, increases soil compaction, and causes crop losses through anoxia and root diseases. Flooding also increases soil erosion. The industry has installed drain tiles to increase dispersal of excess water from fields, but this also contributes to higher river levels and reduced groundwater infiltration.
 - Install drain tiles to remove water from fields
 - Preserve wetlands and other lowlands
 - Minimize off-farm flow of nutrients and pesticides with buffer zones

Extended periods of abnormal warmth or cold:

- Extreme cold or heat, along with abnormal and lengthy temperature anomalies, has impacted crops in recent years. Cold and wet springs can delay field preparation and planting. Extended heat, especially when combined with drought, can reduce crop yields or decimate the entire season's product.
 - ° Plant more heat tolerant crops
 - Increase use of temperature-controlled housing for livestock
 - ° Increase use of pesticides
 - Utilize seasonal weather forecasts for strategic planting decisions.

Extreme dryness or drought:

 Severe droughts — excluding 2003, from 2000 to 2010, crop losses accounted for nearly all of the direct damages resulting from droughts in the United States. Severe droughts in the past decade have affected large areas of the Southeast, Midwest, South, and West. Farmers have increased



their installation of center pivot irrigation systems to help offset both short-term dryness and longer term drought.¹⁶ Drought can also force livestock herds to be culled due to the high cost or unavailability of water or the reduced productivity of rangeland.¹⁷

- Install center pivot irrigation systems
- Use precision irrigation systems
- Plant more drought tolerant crops

Conclusion

Recent weather and climate variations have produced a large number of outlier events. These events have been significantly impactful to both regional and local areas around the United States. While some of these events have been unusual in their severity, societies increasing exposure and vulnerability to these events are resulting in greater disruptions. Extreme rainfall, drought, and extended periods of abnormal warmth or cold are the most frequent outlier weather events taking place. Flooding events have historically been the most costly and their increased frequency suggests that a priority be placed in that area. Each of these more common outlier hazards can impact individuals, businesses, and government agencies. Awareness of the hazards and their impacts can help to formulate plans and enable actions that may help offset the risks associated with these events.

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16. USDA. 2012, Climate Change and Agriculture in the United States: Effects and Adaptation. http://www.usda.gov/oce/climate_change/effects_2012/CC%20 and%20Agriculture%20 Report%20(02-04-2013)b.pdf 17. National Drought Mitigation Center, Checklist of Historical, Current and Potential Drought Impacts. http://drought.unl.edu/portals/0/docs/checklist.pdf