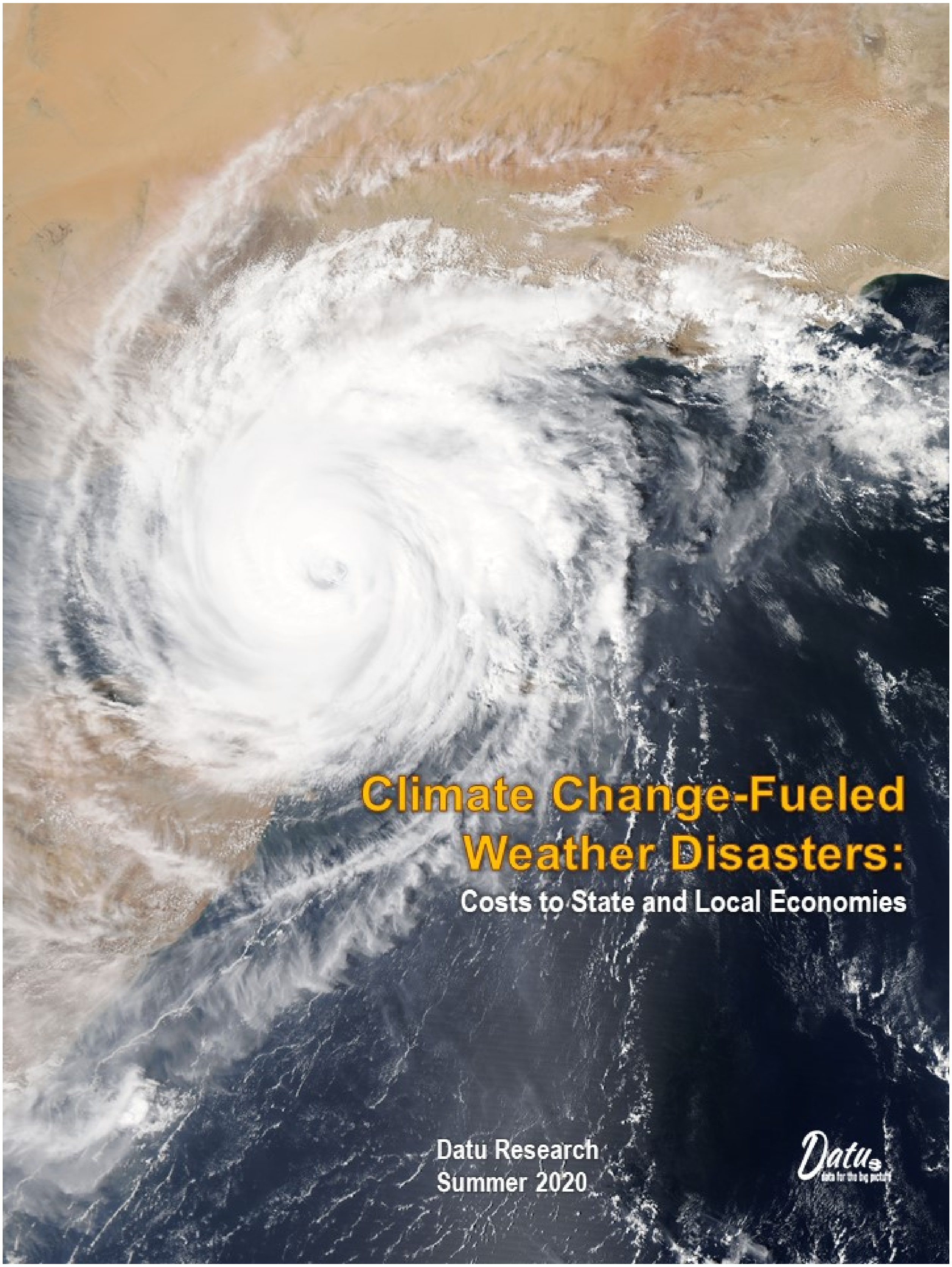

Climate Change-Fueled Weather Disasters:

Costs to State and Local Economies

Datu Research
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ABOUT THIS REPORT
This report was prepared for Environmental Defense Fund.
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OPINIONS AND COMMENTS
The opinions or comments expressed in this report are not necessarily endorsed by organizations mentioned or individuals interviewed. Errors of fact or interpretation remain exclusively with the authors. We welcome comments and suggestions.

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Methodology

This report is based on a literature search of available information on the costs of climate change-fueled extreme weather events. It primarily draws on data from four publicly available resources: i) The National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (NCEI) Billion-Dollar Weather and Climate Disasters database, ii) The NOAA Storm Events database, iii) The United States Department of Agriculture (USDA) Cause of Loss Historical Data, and iv) The US Small Business Administration (SBA) Disaster Loan Data. Details for each of these sources are below.

For all multi-year comparisons of billion-dollar disaster costs, data has been CPI-adjusted to 2019 dollars to enable an accurate comparison of costs across long periods, such as 1980 through 2019. For our selected disasters, however, state and local data in tables and figures is, in each case, all from a single year, and so are not adjusted, but appear as reported in the above sources. This information represents the financial and economic strain that regions, states, counties, and towns face in extreme weather. Because the sources rely on reported data, often from multiple agencies with different reporting requirements—and many cases of no data reported—most of the total cost numbers in this report are almost certainly an undercount.

i) NOAA National Centers for Environmental Information (NCEI) US Billion-Dollar Weather and Climate Disasters Database

All "total cost" data for each disaster is from the NOAA NCEI US Billion-Dollar Weather and Climate Disasters database. Our analysis draws on NCEI's record of weather and climate disasters that each have caused damages equaling or exceeding $1 billion. We used this data to analyze trends across seven categories of events, highlighting changes in the frequency, intensity, and costs of each event category. Characteristics of the NCEI database include the following:

- Event types monitored: Tropical Cyclones (hurricanes), Severe Storms, Floods (inland), Winter Storms, Freezes (crop freeze events), Droughts, and Wildfires.
- Events occurred from 1980 through 2019.
- Only disasters with costs equaling or exceeding $1 billion, adjusting for inflation, are included. All event costs have been adjusted for inflation using the Consumer Price Index (CPI). They have been CPI-adjusted to 2019 dollars so that the economic costs of events can be easily compared across many years.
- The data accounts for total direct costs—both insured and uninsured. In some cases, insured loss data has been re-scaled to account for uninsured and underinsured losses.
- The total cost attributed to each disaster incorporates data from both public and private sources, including Insurance Services Office (ISO); Property Claim Service (PCS); FEMA; Presidential Disaster Declaration (PDD) assistance; National Flood Insurance Program (NFIP); USDA; National Agricultural Statistics Service (NASS); National

Interagency Fire Center (NIFC); Energy Information Administration (EIA); US Army Corps of Engineers (USACE); Risk Management Agency (RMA); State agencies.

- According to the NOAA website, costs incorporated into estimates include:
    - Physical damage to residential, commercial, and government or municipal buildings
    - Material assets within a building
    - Time element losses like business interruption
    - Vehicles and boats
    - Offshore energy platforms
    - Public infrastructure like roads, bridges, and buildings
    - Agricultural assets like crops, livestock, and timber
    - Disaster restoration and wildfire suppression costs
- Total cost estimates should be considered conservative for several reasons:
    - Cost estimates do not account for natural capital or asset losses, losses related to health care, or values associated with loss of life.
    - Drought event costs have high uncertainty because of the lower insurance coverage associated with this event type. An estimated 70% of all eligible acres across all states are insured. Of those insured, most producers elect to cover 70% of their crop yield (USDA/RMA 2012).
    - Flood event costs have high potential uncertainty because assets damaged from these events typically have less insurance coverage.
    - There is higher confidence in costs of local storm events because of more complete coverage of wind and hail damage (A. B. Smith and Matthews 2015).

ii) NOAA National Centers for Environmental Information Storm Events Database

Our report draws on the NOAA Storm Events database to assess property damages from the events we selected. Characteristics of the NCEI Storm Events Database include the following:

- Property damage is recorded daily for each relevant county or weather zone and corresponds to a specific event type, such as hurricane, tornado, or flash flood. Database users can filter data to obtain property damage records for particular states or counties, dates, and event types.
- Data is available for events from 1950 to 2019.
- Data in the Storm Events Database is collected and entered by employees of NOAA's National Weather Service (NWS) on an ongoing basis. Narratives about each weather event are entered by NWS personnel. There is some reliance on private citizens to report damage to NWS by submitting photographs and descriptions; thus, costs may be misestimated or under-reported.
- Property damage is recorded in terms of reported-year dollars. They are not adjusted for inflation. As such, NOAA-reported property damage in tables throughout the report appears in terms of event-year dollars, unless otherwise specified.

iii) US Department of Agriculture Risk Management Agency Monthly Crop Loss Data

Our report draws on the USDA Monthly Crop Loss Data to assess damages to the agricultural sector for the events we selected. Characteristics of the USDA Monthly Crop Loss Data include the following:

- Files containing monthly crop indemnities are available on the USDA Risk Management Agency site.
- Files are available for every year, including 2020, dating back to 1989.
- Indemnity amounts are reported by month, commodity name, and cause of loss by each county in every state.
- "Indemnity amount" is defined by USDA as "the total amount of loss for a designated peril." Indemnity amounts are reported by crop insurance policyholders.
- Since crop loss is recorded on a monthly, rather than daily basis, the figures throughout the report serve only as an estimate of the impacts of a given event on crop yields.
- Crop indemnity data points are recorded in reported-year dollars. Unless otherwise specified, USDA-reported crop indemnity amounts in tables throughout our report appear in terms of event-year dollars.

iv) Small Business Association Disaster Loan Program Data

Our report draws on the Small Business Association Disaster Loan Program Data to assess businesses' losses from the events we selected. Characteristics of the SBA Disaster Loan Program Data include the following:

- Files containing losses to businesses are available for download on the SBA website under Open Data Sources.
- Data is organized into files for each fiscal year from FY 2008 to FY 2018.[1]
- Data is available at the state, county, and city levels.
- Total verified losses are broken into real estate losses and content losses:
    - Real estate losses refer to damage to property consisting of land or buildings and other immovable business property.
    - Content losses include items such as inventory, machine and equipment, and leasehold improvements.
- Total verified losses are calculated by an SBA verifier who inspects the properties of loan applicants to estimate their total physical losses.
- Assistance from the SBA is offered to businesses and private nonprofit organizations of all sizes.
- Because SBA disaster loans are provided for declared disasters only, business loss data was only available for events that were associated with a FEMA Major Disaster Declaration.

[1] Fiscal year is October 1 through September 30.

- Data in the files was not edited after entry into the SBA's Disaster Credit Management System, and therefore has not been adjusted for inflation. SBA-reported business losses in tables throughout the report are reported in terms of event-year dollars unless otherwise specified.
- The data does not connote official Federal reports and cannot be considered precise estimates of losses to businesses for two primary reasons:
    1) Assistance from the SBA is for damages not covered by insurance. Although total physical damage to a property is estimated before a loan officer reviews any insurance or other recoveries, the verified loss figure does not represent total losses to all business from a disaster. Only companies with uninsured losses will likely apply for a SBA loan. An estimated 40 to 60 percent of commercial losses induced by natural disasters are covered by insurance (A. B. Smith and Matthews 2015).
    2) The data does not reflect precise loss values because the first verified losses recorded are not revised to reflect any changes.

Event Type and Disaster Selection

Our report analyzes how climate change-fueled extreme weather events have impacted state and local economies. Each chapter focuses on an event type tracked by NCEI's Billion-Dollar Weather and Climate Disasters database. For each, we first consider how climate change has contributed to observed trends, ensuring that any statements we make about the link between climate change and weather events are supported by peer-reviewed journal articles. We then look at trends in the frequency and costs of the relevant event type, dating back to 1980. For each category, we selected at least one recent billion-dollar disaster.

We based our selection of weather events on several parameters. First, all disasters selected occurred between 2016 and 2018 to provide the most recent picture. Second, weather events chosen represent the region in which they tend to happen, avoiding those that were not typical, historically. Third, we selected events reflective of the cost average for the type of event and region. Options were sometimes limited by the availability of data in our primary databases described above. Fourth, we attempted to select events evenly across most of the seven climate regions of the United States. These selection criteria helped provide a reliable picture of what may be expected throughout the United States going forward.

After an overview of each selected disaster, we zoom in on the costs to a state, and then a community, that were severely affected. Feature states for each event were chosen based on which state had the highest reported costs of damages, per the primary data sources described above, and depending on the nature of the event. For example, for events like severe storms, we expect property damages to be the salient cost. For freezes, we would expect minimal property damage, but substantial crop loss. We took into consideration whether an event was typical historically for a given state. Final selection of feature states further depended on the availability of relevant quantitative news and economic reports.

To develop our county-level narratives, we conducted a comprehensive news search, including online newspapers and local television news outlets. Where available, this research also integrated studies and reports that examined the economic and social impacts of disasters at the state and local levels. Some disasters were covered extensively by published research that empirically examined their economic, environmental, and social effects; others were not similarly covered. To augment some narratives based on desk research, we conducted interviews with state and local officials.

Acronyms

Abbreviation	Name
ABCWUA	Albuquerque Bernalillo County Water Utility Authority
CBO	Congressional Budget Office
CDBG	Community Development Block Grant
CDBG-DR	Community Development Block Grant Disaster Relief
CPI	Consumer Price Index
CO_2	Carbon Dioxide
EF	Enhanced Fujita
EIA	Energy Information Administration
EIU	Economist Intelligence Unit
EPA	Environmental Protection Agency
FCS	Flood Controls System
FEMA	Federal Emergency Management Agency, US Dept. of Homeland Security
GAO	Government Accountability Office
GDP	Gross Domestic Product
GSP	Gross State Product
GRI	Growth Reinvestment Initiative
HUD	US Department of Housing and Urban Development
HVAC	Heating, Ventilation, and Air Conditioning
IA	Individual Assistance
IGG	International Growth Group
III	Insurance Information Institute
IPCC	Intergovernmental Panel on Climate Change
ISO	Insurance Services Office
MIT	Massachusetts Institute of Technology
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NASS	National Agricultural Statistics Service
NBER	National Bureau of Economic Research
NCA	National Climate Assessment
NCEI	National Centers for Environmental Information, NOAA
NDDA	North Dakota Department of Agriculture
NDMC	National Drought Mitigation Center
NEEF	National Environmental Education Foundation
NFIP	National Flood Insurance Program
NIBS	National Institute of Building Sciences
NIFC	National Interagency Fire Center
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NPCC	New York City Panel on Climate Change

NPS	National Park Service
NRDC	Natural Resources Defense Council
NSSL	National Severe Storms Laboratory
NWS	National Weather Service, NOAA
NYT	New York Times
OSHA	US Occupational Safety and Health Administration
PA	Public Assistance
PCS	Property Claim Service
PDD	Presidential Disaster Declaration
RCP	Representative Concentration Pathway
RGWF	Rio Grande Water Fund
RMA	Risk Management Agency
RMI	Rocky Mountain Institute
SBA	US Small Business Administration
SBS	Department of Small Business Services
STDEC	South Texas Economic Development Center
TNC	The Nature Conservancy
USACE	US Army Corps of Engineers
USCB	US Census Bureau
USDA	US Department of Agriculture
USFS	US Forest Service, US Department of Agriculture
USGCRP	US Global Change Research Program
USGS	US Geological Survey, US Department of Interior
WWA	World Weather Attribution

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Executive Summary

Earth's warming climate is fueling the increasing frequency and intensity of weather and climate disasters. A growing body of climate science research suggests connections between anthropogenic climate change and worsening extreme weather events, including hurricanes, floods, severe storms with tornadoes, winter storms, freezes, droughts, and wildfires. Increasingly, these weather disasters result in unprecedented economic costs, making clear the need to invest in bold action to reduce greenhouse gas emissions—the underlying drivers of climate change. In addition, since weather disasters will continue to occur even in the best future climate scenarios, it is clear that we will need to adapt to the impacts of climate change already underway. In the most vulnerable geographies, such action may entail managed retreat—shifting land uses rather than rebuilding in harm's way.

In this report, we draw on the best available scientific research to show the varying degrees of connection between climate change and each type of weather disaster. To gain insight into the price Americans are paying for worsening weather disasters, we summarize data from the National Oceanic and Atmospheric Administration (NOAA) Billion-Dollar Weather and Climate Disasters database and other public sources.

NOAA has tracked the costs of the most extreme weather events in the United States since 1980, estimating the total direct cost of each event that caused $1 billion or more in damage (adjusting all costs to 2019 dollars). No state is untouched by these billion-dollar disasters.

Drawing on NOAA's Billion-Dollar Weather and Climate Disasters database and other publicly available data, we present the costs of nine recent weather disasters across the contiguous United States—including one each from seven NOAA-designated extreme event categories, and a second one from the hurricane category and the flooding category.[2] For each recent disaster selected, we focus on the hardest-hit state among all the states affected; for instance, in the case of Hurricane Harvey in 2017, the disaster severely affected Texas, Louisiana, Mississippi, Alabama, and North Carolina, at an estimated total direct cost of $130 billion. In our discussion, we feature Texas, which is estimated to account for at least $100 billion of the total cost. For a list of the disasters we selected, the states severely affected, and the state we feature for each disaster, see Table 1.

[2] For disaster selection criteria, see Methodology section, page vii.

Table 1. Selected US Billion-Dollar Disasters, Their Total Direct Costs, and Affected States Featured in This Report

Year	Disaster	States Severely Affected	Total Direct Costs*	State Featured in This Report
2017	Hurricane Harvey	TX, LA, MS, AL, NC	**$130B**	Texas
2017	Hurricane Irma	FL, GA, PR	**$52B**	Florida
2018	Severe Weather and Tornadoes	IA, CT, MA, NY, PA, NJ, MD, WV, VA, OH, IN, IL, MO, KS, OK, TX, CO	**$1.6B**	Iowa
2016	Inland Flooding Matthew**	NC, FL, SC, GA, VA	**$5B to 10B**	North Carolina
2018	Inland Flooding Florence**	NC, SC	**$20 to 50B**	North Carolina
2018	Northeast Winter Storm	NY, CT, MD, VA, PA, NJ	**$2.3B**	New York
2017	Southeast Freeze	GA, SC, NC, FL, AL, MS, TN, KY, VA	**$1.1B**	Georgia
2017	Northern Plains Drought	ND, SD, MT	**$2.6B**	North Dakota
2017	Western Wildfires	CA, MT, WA, OR	**$18.7B**	California

Source: NOAA 2020. *CPI-adjusted to 2019 dollars. **States affected and total direct costs are for Hurricane Matthew and Hurricane Florence, respectively; total direct costs are the NOAA-estimated range for NC only.

Harbingers of the future, these costs are borne by homeowners, businesses, farmers, ranchers, taxpayers, and government. In the era of the COVID-19 pandemic, especially, federal, state, and local governments will be hard-pressed to provide adequate resources for response and recovery from weather disasters. As of this writing, COVID-19 federal aid is estimated to be in the range of $1 trillion to $3 trillion (Restuccia and Davidson 2020). Even before the pandemic, federal and state disaster resources were already strained, with climate change-fueled extreme weather events increasing in frequency and intensity, and more people living in at-risk locations.

The US Government Accountability Office (GAO) estimates that between 2005 and 2019, the federal government, including FEMA and other agencies, has spent at least $450 billion on weather disaster assistance, an average of $30 billion per year (GAO 2019). It is easy to imagine that, in the face of the COVID-19 pandemic, a similar level of aid may not be available for weather disaster assistance.

The rapidly escalating costs of weather disasters are only a lower bound to what is anticipated if greenhouse gas emissions continue unabated and global temperatures continue to rise. Climate models project that even with a moderate increase in greenhouse gas emissions, by the end of this century, the frequency of Category 4 and 5 hurricanes in the Atlantic Basin could increase by 45-87 percent, putting the continental United States at risk. In the absence of climate policy to rapidly reduce emissions, we can also expect greater frequency or intensity of five other categories of weather disaster (see Table 2).

Table 2. US Weather Disaster Projections in Absence of Climate Policy to Reduce Emissions

Disaster	Projected Changes of Extreme Weather Events in Absence of Climate Action
Hurricanes	Climate Models project a 45-87% increase in the frequency of Category 4 and 5 hurricanes in the Atlantic Basin by century's end for a moderate increase in greenhouse gases (Knutson et al. 2013). Some of the most dangerous hurricanes were formerly designated as storms with a one-percent likelihood of occurrence in a given year. Scientists find that, with climate change continuing at current rates, such storms could happen every 5-10 years (Emanuel 2017).
Severe Storms	Scientists anticipate an increase in the frequency of storms, particularly over the Midwest and Southern Plains. An increase in storm intensity is expected due to changes in temperature, humidity, and wind, which control the intensity of convective storms (USGCRP 2017b).
Floods	As the world continues to warm, scientists anticipate continued increases in heavy precipitation events, suggesting a likely increase in flood disasters—with significant variations geographically (IPCC 2013b). By the end of the century, the area of the one-percent-annual-chance floodplain could increase by about 30 percent, with the most extensive changes being in the Northeast and the Great Lakes regions (USGCRP 2017a).
Freezes	In a warming world, researchers expect vulnerability to crop-damaging freezes to increase, with early onset of spring occurring (Barcikowska 2019) by mid-century, at nearly twice the rate previously observed (Labe, Ault, and Zurita-Milla 2017). Unless the last freeze date also changes at that same rate, the agricultural economy is at risk of large-scale losses (Reidmiller et al. 2018).
Drought	With continued rising temperatures, scientists anticipate longer dry periods in semi-arid regions of the midlatitudes and subtropics, such as the US Southwest (IPCC 2013a). Scientists suggest that increased evaporation due to rising temperatures may outpace increased precipitation, leading to more frequent and intense drought conditions across the continental United States (USGCRP 2017d). Researchers at NASA and Columbia University suggest the US Southwest could experience "megadroughts" that last over 30 years (Gray and Merzdorf 2019).
Wildfire	Climate models project a continued increase in frequency and intensity of wildfires with rising temperatures (Kenward, Sanford, and Bronzan 2016). Higher wildfire risks are expected across the West and Southeast. Scientists suggest that in the western United States, by mid-century, the area burned each year could rise by a factor of 2-6 times from present levels (Reidmiller et al. 2018).

Key takeaways from this report include the following:

1) **Since 1980, the number of extreme weather events per year has increased fourfold, and the annual direct cost of the disasters has increased fivefold.** During this period, the United States has had a total of 258 such weather and climate "billion-dollar" disasters, at a total direct cost of more than $1.75 trillion (NOAA 2020a).
2) **Since 1980, the direct costs of one US disaster category—hurricanes—have increased eleven-fold.** Driving factors include climate change and shifting land-use patterns that place more people and properties at risk. The population in counties prone to hurricane damage grew at least 22 percent faster than the overall US population. The Congressional Budget Office (CBO) projects that by 2075, 10 million people will be living in hurricane-damaged counties (CBO 2016).
3) **All 50 states have suffered from at least one billion-dollar weather disaster, but in five unlucky states, all seven types of disaster have hit repeatedly.** North Carolina, Georgia, Alabama, Mississippi, and Texas have each endured several billion-dollar hurricanes, severe storms, floods, winter storms, freezes, droughts, and wildfires (NOAA 2020a).
4) **As the world continues to warm, climate change-fueled weather disasters will become more frequent, more severe, and more costly.** In the absence of climate action, we can expect a future with many more billion-dollar hurricanes, floods, severe storms, climate-damaging freezes, drought, and wildfires. For every 1°C of warming, future damage is projected to cost roughly 1.2 percent of Gross Domestic Product (GDP)—an amount that, in 2019 terms, would be roughly $257 billion annually. This scenario can be significantly mitigated by substantially reducing greenhouse gas emissions.
5) **Since it is only possible to slow the rate of future warming—but not reverse it, at least in the coming decades—it is crucial to adapt, build resilience, and in some cases, retreat from disaster-prone areas.** Adaptation and resilience projects such as elevating buildings or rebuilding coastal wetlands are a worthwhile investment in limiting damage from future disasters. Protecting people from areas that repeatedly get flooded or burned may require relocating rather than continuing to rebuild.

The extreme weather events highlighted in this report are increasing in frequency, severity, and cost to taxpayers. Mitigating the driving force of climate change—greenhouse gas emissions—requires federal, state, and local governments to take immediate action. Meanwhile, the impacts of climate change are already underway; we can no longer rely solely on mitigating greenhouse gas emissions to prevent future damages. In the face of continued, climate change-fueled weather disasters, it is also critical that government leaders take preemptive action to adapt vulnerable communities to our changing climate.

I. Introduction

On the evening of October 8, 2016, residents of the small town of Fair Bluff, North Carolina went to bed knowing that Hurricane Matthew was on its way. But with at least two or three counties separating Fair Bluff from any coastline—and no local history of significant flooding since 1928—it didn't seem like an emergency. No one in Fair Bluff seemed to expect Matthew to dump 13 inches of rain on them. Then, early the next morning, many townspeople woke up to find the Lumber River surrounding their beds. Less than two years later, in 2018, Hurricane Florence arrived, also bringing massive rainfall inland. Like Matthew, Florence again put Fair Bluff's downtown underwater for two weeks, destroying homes and livelihoods. Witnessing the town's ongoing struggle to recover, one reporter observed that if another hurricane arrives, Fair Bluff "could become one of the United States' first climate crisis ghost towns." (Graff 2019).

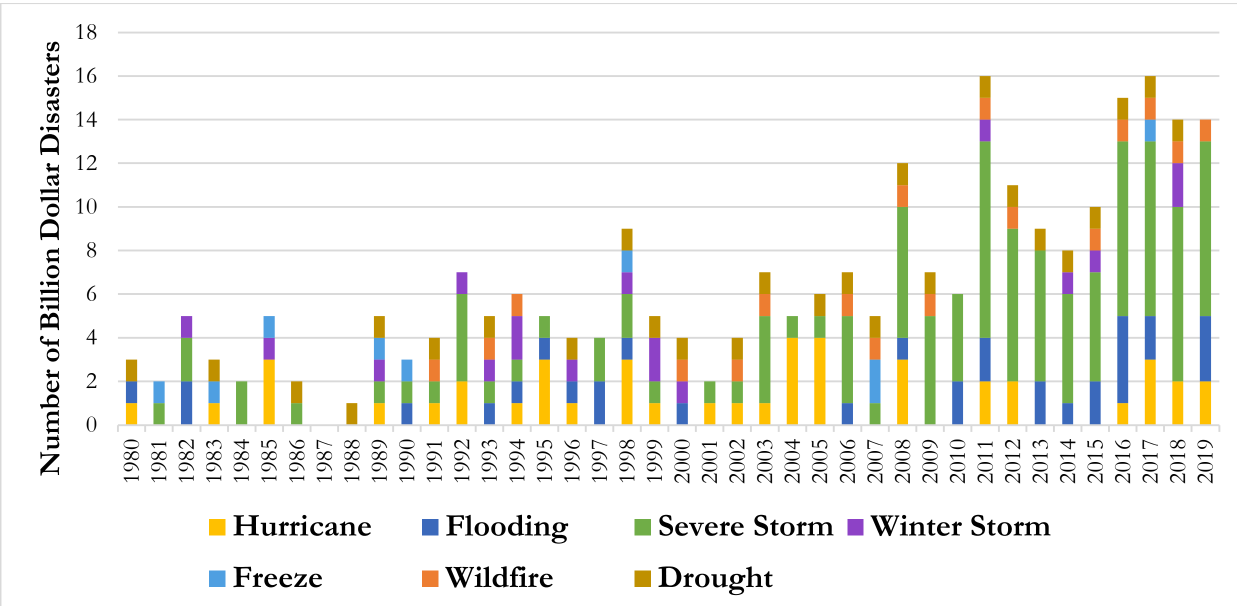
Eastern North Carolina is a dramatic example of a larger pattern in which a warming climate is fueling the increasing frequency and intensity of weather and climate disasters. Temperature records show that 19 of the hottest 20 years on record have occurred since 2001 (NCEI 2020a).

A warmer Earth causes shifts in air circulation and weather patterns—and more evaporation and thus moisture in the air—both of which have profound impacts on extreme events. There is now around seven percent more moisture in the atmosphere than during preindustrial times (USGCRP 2017c), so when it rains, there can be more rain, and when it snows, there can be more snow. In the US Northeast, heavy downpours now contain 55 percent more rain than in the 1950s (USGCRP 2017c), and the most significant 2-day snow totals in more than 40 percent of US counties have occurred since 1980 (Climate Central 2017). More moisture in the air, combined with warming oceans, intensify tropical storms and hurricanes (NOAA n.d.-b). Rising sea levels from expanding seawater and melting glaciers lead to even more damaging storm surges.

Global warming drives not only the wet extremes; it also can make dry regions drier. In arid areas, warmer temperatures can dry out land from increased evaporation, which can worsen drought conditions and make them more likely to occur. In the mountains, earlier, faster snowmelt during springtime can reduce water supply in the summer. Whatever rainfall happens is more prone to come in shorter, more intense bursts—making it hard for soil to retain moisture and for groundwater to recharge, posing a double threat to water supplies for farmers, ranchers, and cities (Cook, Mankin, and Anchukaitis 2018). Drought conditions also fuel wildfires. Since the 1970s, the annual average wildfire season in the western United States has increased by months and burns six times as many acres (Kenward, Sanford, and Bronzan 2016).

Across the United States, the number of weather and climate catastrophes has climbed steeply in recent years. NOAA tracks "billion-dollar disasters," or those that reach or surpass $1 billion in direct costs—in other words, the damage, insured and uninsured, to property, infrastructure, and agriculture, as well as disaster relief and wildfire suppression. These direct costs are, by definition, an undercount since they do not include losses to natural assets, health, or loss of life. Even without these harder-to-quantify costs, the direct costs are staggering. Using the CPI to adjust all direct costs to 2019 dollars, NOAA calculates that the annual number of disasters exceeding the billion-dollar threshold has increased fourfold, from around three disasters in the 1980s to 12 in the most recent decade (see Figure 1). Since 1980, the United States has had a total of 258 such weather and climate billion-dollar disasters, at a total direct cost of more than $1.75 trillion (NOAA 2020a).

Figure 1. Number of US Billion-Dollar Disasters by Disaster Category, 1980-2019



Source: NOAA 2020.

Similarly, the average annual cost of billion-dollar disasters is rising steeply. Throughout the 1980s, the average cost was $17 billion per year; since 2010, in contrast, the average cost has grown to $84 billion per year (all figures CPI-adjusted to 2019 dollars). This is nearly a five-fold increase. Much of the rise in costs is explained by a combination of loosely regulated land use development and climate change effects. In recent years, more and more homes and businesses have been built in areas that are vulnerable to events such as hurricanes, flooding, or wildfire. CBO noted that in the decade of 2000-2010, population in counties prone to hurricane damage grew 22 percent faster than the US rate. The CBO study concluded that continuing coastal development will likely further amplify damage from hurricanes. Estimating that 1.2 million people currently live in counties with substantial hurricane damage—and taking into account the effects of coastal development and climate change—the authors projected that by 2075, 10 million people will be living in hurricane-damaged counties (CBO 2016).

Recent advances in climate science have enabled us to assess how human-caused climate change made certain events more severe or likelier to happen. Computer models can simulate particular, extreme weather events, such as heatwaves and storms, with and without human influence, to analyze the role that climate change played. For example, when Hurricane Harvey inundated Texas with more than 60 inches of rain in some areas, several studies concluded that global warming made this storm at least three times likelier to occur than it would have been, absent global warming (NAS 2019).

This report presents detailed data from nine recent weather disasters across the contiguous United States: two hurricanes, a severe storm with tornadoes, two tropical cyclone-related inland floods, a winter storm, a freeze, drought, and wildfire. All of these event

The health costs of weather disasters do not appear to have been systematically quantified. However, a team of researchers in 2011 studied six climate-change-related events that had struck the United States between 2000 and 2009, including heat waves, hurricanes, infectious disease outbreaks, ozone pollution, river flooding, and wildfires. They found more than $14 billion in health costs; 95 percent of this total was attributed to premature loss of life (Knowlton et al. 2011).

NRDC researchers have further studied the human health impacts of wildfire smoke, including deadly pollutants (such as fine particulate matter), linked to significant health risks such as respiratory infections, cardiac arrest, and lung cancer, among others. They estimated that in 2011, the US area affected by smoke from wildfires was nearly 50 times larger than the acreage burned (Limaye and Constible 2019). Further, using best available public health science from a previous EPA-led study (Fann et al. 2017), the NRDC team estimated that health costs linked to 2012 wildfire smoke in California alone amounted to $6.5 billion (Limaye and Constible 2019).

categories have connections to climate change to varying degrees, and our analysis draws upon the growing body of climate science research that characterizes these relationships.

We rely on NOAA's Billion-Dollar Weather and Climate Disasters database for estimated total direct costs of each disaster. We provide selected cost subcategories (presumed to be included in NOAA's total cost estimates), from relevant federal agencies.

Included in our analysis are projections of future increases in the intensity and frequency of weather disasters—should governments, corporations, and citizens fail to take action to curb greenhouse gas emissions. To protect vulnerable geographies in the meantime will require a parallel effort to increase resilience to climate change-fueled weather disasters. In this report, we present three case studies of resilience plans in US locations exposed to sharply growing risk. Our examples—a small city in the Midwest that anticipates a return of catastrophic flooding, a metropolis in the Northeast that risks a repeat of a devastating hurricane, and an entire watershed in the Southwest that is bracing for a future of potentially crippling drought. In the coming decades, these efforts may prove to be a crucial complement to the public and private action necessary to reduce the emissions that are warming the climate.

II. Hurricanes

- Estimated total direct cost of Hurricane Harvey in 2017: **$130 billion**
- Number of billion-dollar hurricanes that have hit Florida in the past four years: **4**
- Projected increase in the frequency of Category 4 and 5 hurricanes in the Atlantic basin: **45-87%**

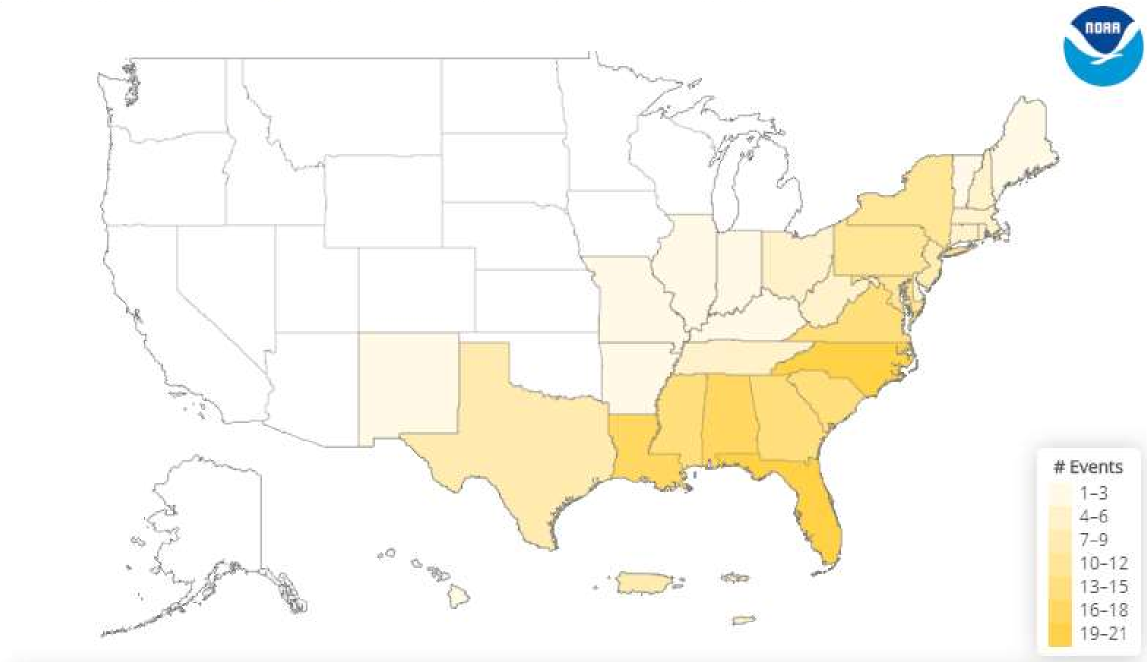
Hurricanes have been described as nature's fiercest fury. A hurricane first forms as a small disturbance in or near a tropical ocean. It will increase in intensity if the water is warm enough, and atmospheric conditions provide enough moisture, along with uniform winds. In the Atlantic, where most US hurricanes form, the storm evolves into a tropical depression, strengthening into a tropical storm. When the winds exceed 74 miles per hour, it is considered a hurricane (Berardelli 2019).

Climate change can influence the development, track, strength, and impact of hurricanes. Scientists have found that the warming climate is making storms shift poleward (Kossin, Emanuel, and Vecchi 2014) and intensify more rapidly (Bhatia et al. 2019). It is also making storms stronger (Holland and Bruyere 2013), wetter (Patricola and Wehner 2018), and slower (Kossin, Emanuel, and Vecchi 2014). Thus, although it remains unclear whether hurricanes are more frequent nowadays—partly due to a lack of reliable records beyond the satellite era—it appears that they are becoming more intense (Knutson et al. 2019).

Several dynamics of our changing climate affect the intensity of hurricanes. First, warmer air contains more moisture, leading to heavier rainfall; second, warmer ocean temperatures can fuel a storm, potentially increasing wind speed and causing it to intensify more quickly; third, shifting circulation patterns can influence the location and speed of the storm; and fourth, the warming ocean causes seawater to expand, which combines with melting land-based ice to contribute to sea-level rise. This, in turn, increases storm surge and exacerbates coastal flooding. Studies show that since the 1960s, rising sea level has already made high tide flooding 5-10 times more frequent in a number of US coastal areas (Reidmiller et al. 2018). This is expected to continue to worsen flooding associated with coastal storms (Reidmiller et al. 2018).

The United States is most vulnerable to hurricanes in the states along the Atlantic Coast and the Gulf of Mexico (see Figure 2). In the forty years since 1980, many of these states have been repeatedly slammed by billion-dollar hurricanes. For instance, Louisiana has suffered 17 different billion-dollar hurricane disasters; for North Carolina, that number is 20, and for Florida, 21. Florida has the unlucky distinction of being hit by a billion-dollar hurricane for the past four years in a row—Hurricane Matthew (2016), Irma (2017), Michael (2018), and Dorian (2019).

Figure 2. Number of Billion-Dollar Hurricane Disasters, Affected States, 1980-2019



Source: NOAA 2020. Note: Billion-dollar designation is based on CPI-Adjusted costs (2019 dollars).

The annual cost of billion-dollar hurricanes appears to be trending upward. Measured in CPI-adjusted 2019 dollars, the average annual cost of hurricane disasters in the 80s was $3.8 billion; in the 90s, the average annual cost nearly tripled, to $10.5 billion, in the 2000s, it tripled again to $36.5 billion, and in the most recent decade, it topped $43.8 billion (NOAA 2020a). Put differently, since the 1980s, the annual average cost of hurricanes has seen a more than 11-fold increase. The soaring cost is partly explained by a changing climate and increased intensity of storms, partly by largely unregulated coastal development, which has put far more people and properties at risk. Since 1980, shoreline counties along the Gulf and East Coasts have grown by 160 people per square mile, compared with 26 people per square mile in the rest of the contiguous United States (Dapena 2018).

Consistent with the warming climate, recent years have produced several record-breaking US hurricanes; 2019 was the fourth year in a row that a Category 5 storm developed in the Atlantic Basin, breaking previous records (NOAA 2020a). In 2017, Hurricane Harvey (Category 4) stalled over southeast Texas, dumping 60 inches of rain and prompting researchers to calculate that such an event would likely happen only once every 9,000 years (Berardelli 2019). Scientists found that human-caused climate change made record rainfall over Houston around three times more likely to occur and 15 to 38 percent more intense (Risser and Wehner 2017; Wang et al. 2018; van Oldenborgh et al. 2017). That same year, 2017, also brought Hurricanes Irma and Maria, each a Category 5. Hurricane Maria killed nearly 3,000 people in Puerto Rico, including direct and indirect fatalities (Milken Institute of Public Health 2018). The damage to the island was of catastrophic proportions, with flooding, landslides, flattened neighborhoods, a destroyed power grid, and crippled communication networks (NYT 2017).

Climate Models project a 45-87% increase in the frequency of Category 4 and 5 hurricanes in the Atlantic Basin by century's end for a moderate increase in greenhouse gases (Knutson et al. 2013). Some of the most dangerous hurricanes were formerly designated as storms with a one-percent likelihood of occurrence in a given year. Scientists find that, with climate change continuing at current rates, such storms could happen every 5-10 years (Emanuel 2017).

Hurricane Harvey, August 25–31, 2017

One of the most severe hurricanes in recent US history was Hurricane Harvey, a catastrophe that wreaked an estimated $130 billion in damage (NOAA 2020a). It struck Texas as a Category 4 storm on August 25, 2017, with maximum sustained winds of 132 mph—the first hurricane of this strength to hit Texas since 1961. Once making landfall, the system weakened to a tropical storm and slowed, tracking back over southeast Texas and the Gulf of Mexico before making a second landfall in Louisiana. The first five days of the storm produced 30 to 60 inches of rain, 23 tornadoes, dangerous winds, and a moderate storm surge. At times, rain fell at five inches per hour, resulting in catastrophic flooding. Thousands of roads, homes, and businesses were flooded. Federal officials rescued more than 10,000 people, in addition to numerous "good Samaritan" rescues by others (Gallagher 2017).

In terms of scope and peak rainfall, Hurricane Harvey is the most significant tropical cyclone rainfall event to impact the United States since dependable precipitation records began in the 1880s (NOAA 2019).

The US government is increasingly pressed to find adequate funding for disaster recovery, yet the considerable federal spending that does occur still pales compared to the need. In response to Hurricane Harvey, FEMA provided Texas and Louisiana with Public Assistance funds—which typically help local governments remove debris, repair damaged public facilities, and mitigate hazards during recovery. FEMA also provided Individual Assistance funds, which help disaster victims with expenses not covered by insurance, such as home repairs and medical needs. These FEMA efforts amounted to nearly $3.7 billion (see Table 3).[3] In contrast, NOAA-reported property damage, and SBA-reported verified business losses were over $51 billion and over $5.7 billion respectively—and each of these reported losses is likely an undercount.

[3] Unless otherwise noted, all cost data tables in this report represent federal-agency-reported data presumed to be included in the total direct cost estimates from the NOAA Billion-Dollar Weather and Climate Disasters database.

Table 3. Costs of Hurricane Harvey in Affected States, 2017

State	FEMA Public Assistance (PA) & Individual Assistance (IA)	NOAA-reported Property Damage*	SBA-reported Verified Business Losses
Louisiana ***20 affected counties***	PA: $8,380,000	$15,265,000	$433,000
Texas ***53 affected counties***	IA: $1,656,865,000 PA: $2,003,143,000	$51,177,216,000	$5,753,444,000
TOTAL	**$3,663,388,0000**	**$51,192,481,000**	**$5,753,877,000**

Sources: SBA 2018; FEMA 2017; FEMA 2017b; NOAA 2019a. * NOAA numbers are reported by the National Weather Service (in 2017 dollars) and are rounded to the nearest thousand.

Texas Economy

Hurricanes affecting the United States have always had an outsized impact on Gulf Coast states. As climate change exacerbates the intensity of storms, these states may continue to bear the brunt of increased damage. Texas is a case in point. In 2008, Hurricane Ike killed 74 people in the state and caused over $40 billion in total damages (Woodward 2017). This storm was followed by a far more devastating one nine years later, Hurricane Harvey. Of the total estimated $130-billion direct cost of Harvey, Texas is thought to account for at least $100 billion (NOAA 2020a).

Although Hurricane Harvey made landfall near Rockport, Texas, its most significant effects occurred in five Texas counties near the upper Texas coast: Harris, Jefferson, Fort Bend, Orange, and Galveston. It's no surprise that businesses in Harris County, the most populous county in Texas, experienced the most significant real estate loss ($1.7 billion) and $784.4 million of content loss (including items such as inventory, machines, equipment, and leasehold improvements). Harris was followed by Jefferson County, with $370.5 million in real estate losses and $156.8 million in content losses (see Table 4). In total, real estate losses to businesses in these five counties were over $3 billion, and content losses nearly $1.4 billion.

Table 4. Five TX Counties with Highest Business Losses in Hurricane Harvey, 2017

County	SBA-reported* Real Estate Loss	SBA-reported Content Loss**
Harris	$1,699,051,000	$784,369,000
Jefferson	$370,515,000	$156,863,000
Fort Bend	$350,910,000	$143,594,000
Orange	$335,791,000	$139,689,000

Galveston	$308,009,000	$137,042,000
TOTAL	**$3,064,276,000**	**$1,361,557,000**

Sources: SBA 2018. *SBA figures are as reported (in 2017 dollars) and are rounded to the nearest thousand. **Content loss refers to the business content (inventory, machine, equipment, leasehold improvements, and the like) verified by the SBA.

Hurricane Harvey also led to secondary economic effects across the Gulf Coast and US economy. Houston and the entire upper Texas Gulf Coast comprise a strategically important region, providing over a quarter of the nation's oil and gas production and refining capacity. The ripple effects of refinery closures affected jobs and the flow of economic activity throughout the region. As a result of Harvey, US average gas prices rose from $2.35 per gallon before the storm hit, to $2.49 on August 31, 2017, six days after the storm first made landfall (Sider 2017).

Massive government relief programs were central to post-Harvey recovery. According to the South Texas Economic Development Center, FEMA provided nearly $14 billion to affected Texas communities and their residents during the year after the event. NFIP paid out $8.8 billion for flood claims (STEDC 2018). Federal as well as state aid following the hurricane proved crucial to recovery, which raises the question of how state and federal agencies will, in the future, afford to keep pace with increasingly intense calamities fueled by a changing climate.

Harris County

Of the counties affected by Hurricane Harvey, Harris County—home to the greater Houston metropolitan region—suffered the most considerable total economic losses and impacts on businesses. Some areas in the county received more than 50 inches of rain. In addition to business real estate, content, and other property losses, an estimated 300,000 vehicles were flooded across the county (STEDC 2018).

> In Texas, floods formerly designated as 1% annual chance floods are now occurring every 25 years. Houston appears increasingly vulnerable, a problem compounded by geography, land use management, and inadequate infrastructure. Repeat federal flood relief payouts nationwide average about $3,000 per square mile; those in greater Houston, by contrast, are reported to be about $500,000 per square mile (Associated Press 2017).

Harris County lost 23,650 business establishments—or 15% of the county business population (STEDC 2018). This was many more businesses than were lost in other affected counties, primarily because of Harris County's far larger population and concentration of companies. Although direct causality is difficult to determine, business closures matched the pattern of property damage. Shuttered establishments could be closed either for a limited time or permanently (STEDC 2018).

As is the case with most hurricane disasters, Hurricane Harvey had dramatic, lasting impacts on housing availability and financial well-being, especially for minority groups. In a recent survey by the Episcopal Health Foundation, one year after the storm, 27 percent of Hispanic Texans whose homes were severely damaged reported that their homes were still unsafe, compared to 20 percent of Blacks and 11 percent of Whites (Hamel et al. 2018). Many affected residents, especially those who are black, Hispanic, or have lower incomes, reported falling behind in their rent or mortgage payments, borrowing from relatives and friends to cover expenses, or having challenges covering the cost of food. There also appeared to be differences in help based on income. Of those surveyed who had self-reported incomes less than 200 percent of the federal poverty level, only 38 percent reported getting the help they needed, compared to 54 percent of those over the 200 percent federal poverty level (Hamel et al. 2018).

Hurricane Irma, September 6-12, 2017

In early September 2017—less than a month after Hurricane Harvey crawled through Houston—Hurricane Irma slowly tore through the Caribbean and into the continental United States, causing ruin in Puerto Rico, Florida, Georgia, South Carolina, and Alabama. Irma first made landfall on September 6, 2017 as a Category 5 storm on Barbuda in the eastern Caribbean. It brought on 37 straight hours of 185-mile-per-hour winds that extended 50 miles from the hurricane's center. The storm's total death toll was 129 people (Issa, Ramadugu, and Mulay 2018), with costs over $50 billion (Amadeo 2019).

Hurricane Irma is the fifth most costly hurricane on record, at $52 billion (NOAA 2020a). Despite its Category 5 strength, Hurricane Irma was not as destructive as it could have been, since the path missed the most developed areas, particularly in Florida. Had the hurricane's core passed through Miami, even Miami's buildings—which meet the highest wind standards in the country—could not have withstood the 185-mph winds. It is estimated that a direct hit on Miami would have caused $300 billion in damage, including damage to buildings, contents, and interruption to business (Amadeo 2019).

Florida

Of the affected states, Florida suffered the worst. The storm pummeled the Florida Keys, where it made landfall as a Category 4 hurricane early on September 10. Florida Keys residents received orders to evacuate—among the 6.5 million mandatory evacuations in Florida. The Keys suffered twelve inches of rain and a 10-foot storm surge. Statewide, roughly 12 million people lost power. Although the center of the storm did not go over Miami, the city still saw winds of 73 miles per hour, and streets were flooded (NWS 2017). Some areas of southwest and central Florida got rainfall accumulations over 15 inches. The highest total reported rain was 18.65 inches at a home weather station in Citrus County, Florida. River flooding was widespread. Hundreds of businesses and homes were destroyed, and thousands were damaged (NOAA 2020a). NOAA-reported property damage in the state topped $2.2 billion (NOAA 2019a).

Hurricane Irma caused significant damage to Florida's two economic pillars: tourism and agriculture. Roughly 22,000 Miami Beach hotel rooms were all but empty for a full week, at a loss of $25 million (Campo-Flores 2017). Restaurants also were shuttered due to evacuations. Professional sports events were canceled, flights were delayed or canceled, and much of the state's tourism industry was negatively affected as travel came to a halt. The hurricane damaged or destroyed approximately 50,000 recreational boats worth roughly $500 million (Insurance Journal 2017). Even Disneyland closed for two days (Campo-Flores 2017), an action that the park had taken only five times in its history—until the 2020 COVID-19 pandemic, which brought the mandatory shutdown of all such sites.

Agriculture, the state's second-largest industry after tourism, suffered huge losses. As Florida Agriculture Commissioner Adam Putnam noted, "Agriculture took it on the chin. I was surprised by the scale of flooding." (Campo-Flores 2017). One study tallied total crop losses for citrus, other fruits, field crops, vegetables, nursery, and floriculture crops; the estimated total loss was over $1.3 billion (Hodges et al. 2018). Of this, Florida citrus growers—who account for over 70 percent of US citrus production—were especially hurt, with $490 million in losses. Michael Sparks, chief executive of the Florida Citrus Mutual, told the Wall Street Journal, "Every single citrus grove has been affected adversely in some way by Hurricane Irma." (Campo-Flores 2017).

Monroe County

Monroe County, home to the Florida Keys at the southern tip of the state, was devastated. The storm caused significant damage to buildings, homes, roads, internet access, and water and fuel supplies (Jaeger 2017). According to Karen Clark & Company, a catastrophe-modeling firm, of the total insured losses from Irma estimated at $18 billion, much of the structural damage occurred in the Keys (Campo-Flores 2017). FEMA estimated that 65% of homes there suffered major damages, and 25% were destroyed (Almasy, Yan, and Park 2017).

The county received sizeable funding from federal and state agencies, although it appears to pale compared to the county's losses. FEMA provided $62 million to county residents, some going toward assistance for temporary rental housing. Much of the already-tight supply of affordable housing was destroyed in the storm (Gomez 2018). The agency paid for hotel rooms for nearly 3,000 families in Monroe for up to six months. As of 2018, 218 people were still enrolled in the program (Gomez 2018). Support from the state included the Florida Department of Economic Opportunity's "Rebuild Florida Infrastructure Repair Program," which provided $38.7 million for the city of Key West, the city of Marathon, and the Florida Keys Aqueduct Authority (Governor Ron DeSantis 2020).

Although these programs are badly needed, they are also expected to take years to turn around the challenges faced by the Florida Keys. Monroe County business owners overwhelmingly expressed in a recent survey that they lack two things: skilled workers and workforce housing options (Monroe County, FL 2019). Roughly 60 percent of respondents reported they had not received adequate assistance for their business's long-term recovery. More than half said they were experiencing a decline, struggling to keep their doors open, or had already closed in Irma's aftermath.

III. Severe Storms

- CPI-adjusted cost of US billion-dollar severe storms since 1980: **$233.9B**
- Share of this that was since 2010: **66%**
- Reported property damage in July 2018 twisters in Marshall County, Iowa: **$200M**

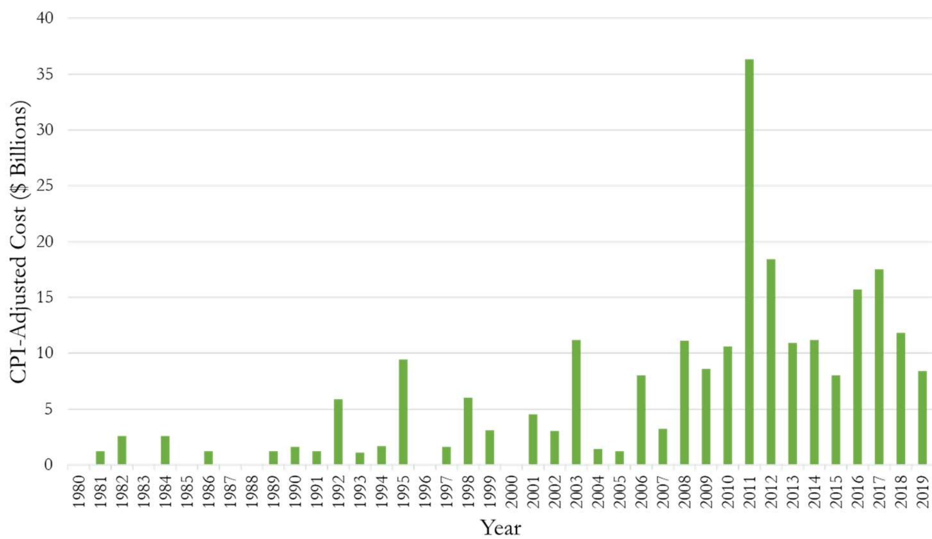
Storms can become severe when thunderstorms, or rainstorms with lightning, are accompanied by strong winds, hail, flooding, or tornadoes. NOAA designates a storm as severe when it includes hail at least one inch in diameter, creates wind gusts of at least 58 miles per hour, or spawns tornadoes (NOAA n.d.-e). To rate the severity of tornadoes, National Weather Service (NWS) uses the Enhanced Fujita (EF) Scale, ranging from EF1 (wind gusts of 65-85 miles per hour) through EF5, with winds over 200 miles per hour (NWS n.d.-b).

Scientists have identified a few mechanisms for how climate change affects severe storms. There is more moisture in the atmosphere in a warmer world, and this can provide energy for storms and increase atmospheric instability—which is a necessary condition for tornado formation. At the same time, tornado activity in the United States has become more variable, and scientists have found with medium confidence that although there are now fewer days per year that have tornadoes, more tornadoes form on these days (USGCRP 2017b).

Observations provide evidence of a global increase in severe thunderstorm conditions and an increase in the number of hail days per year (USGCRP 2017b, 9). Scientists have also found that the frequency of tornado "outbreaks"—or clusters of tornadoes—is increasing, along with the frequency of extremely powerful tornado events. A study in 2016 found that, compared to the 1950s, the largest outbreaks now each include about five more tornadoes that are of at least moderate damage (sufficient to push vehicles off roads, for instance, or overturn mobile homes). The same authors found a trend toward fewer days per year with tornadoes, but more days per year with multiple tornadoes. The reason for this clustering of tornadoes is unknown (Tippett, Lepore, and Cohen 2016).

The rising cost of billion-dollar severe storms reinforces the evidence that storms that do occur are increasingly intense. Between 1980 and 2018, billion-dollar storms (excluding hurricanes) numbered 105, and of these, 60 occurred since 2010 (NOAA 2020a). Four of the five costliest years for severe storms also occurred since 2010 (see Figure 3). Costs peaked at $36.3 billion in 2011, a year marked by deadly tornadoes, including several in cities outside of "Tornado Alley," a multi-state swath that stretches from Texas northward through South Dakota.

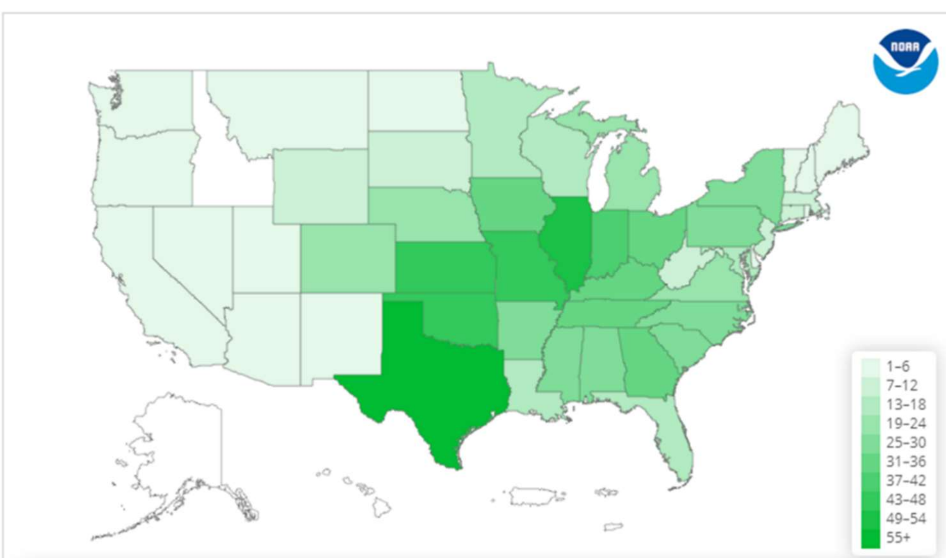
Figure 3. Annual Cost of Billion-Dollar Severe Storm Disasters, 1980-2019



Source: NOAA 2020.

Although storms that produce tornadoes have been disproportionately frequent in Florida and Tornado Alley in the four decades since 1980, nearly all states are vulnerable to severe storms, especially the Southern Great Plains, Midwest, Southeast, and Northeast (see Figure 4). Most recently, the trend has been for tornadoes to become slightly less frequent in Tornado Alley, but more frequent in states east of the Mississippi River (NCEI n.d.-b; Gensini and Brooks 2018).

Figure 4. Number of US Billion-Dollar Severe Storm Disasters, 1980-2019



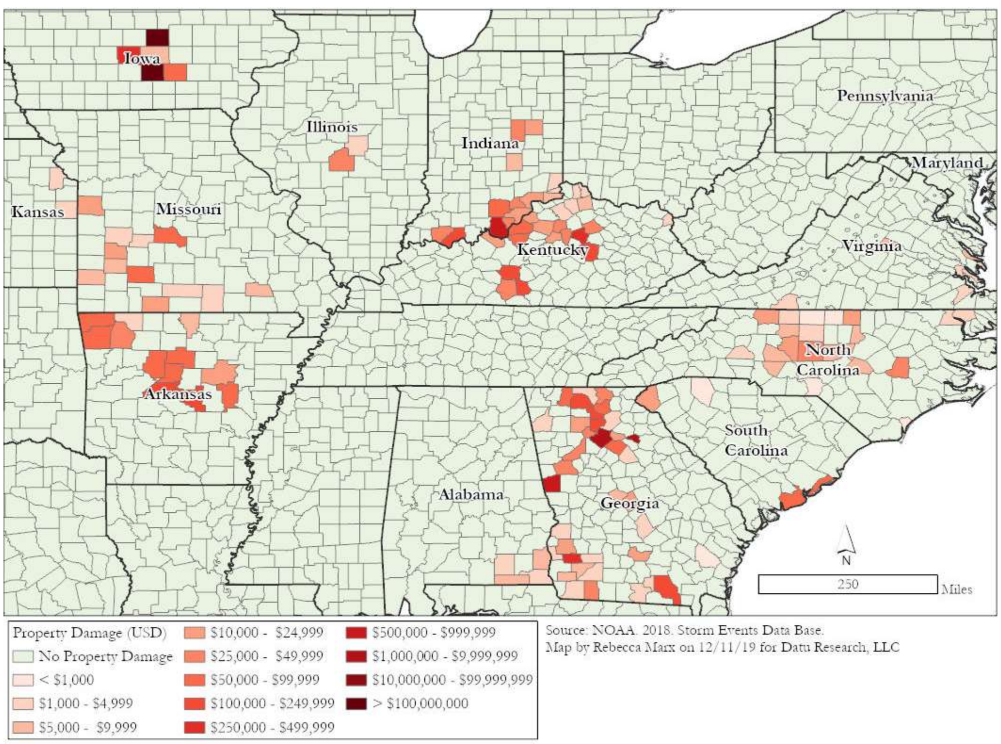
Source: NOAA 2020a. Note: Billion-dollar designation is based on CPI-Adjusted costs (2019 dollars).

If recent trends persist, the future geography of tornadoes could expand, along with the length of time during which they form each year. In the United States, the tornado season (start to end of high tornado activity) is increasing, with the beginning date shifting earlier, and there is more variability in tornado occurrence year-to-year (USGCRP 2017b, 9). Researchers warn that a rapidly warming climate will likely further lengthen the season, in both the fall and spring, associated with increased thermal instability and more frequent severe days (Gensini and Brooks 2018).

Central and Eastern Tornadoes and Severe Weather, July 19-22, 2018

In July 2018, hail, thunderstorms, wind, lightning, and flash flooding caused property and crop damage across the Midwest and Southeast. At least 41 tornadoes tore through 14 Central and Eastern US states with clusters of property damage most acute in Iowa, Arkansas, Indiana, Kentucky, and Georgia (see Figure 5). The storm system began in the Midwest on July 19 and swept eastward, inflicting staggering damage on several local communities by the time it dissipated on July 22. It was one of the most widespread and destructive severe storm events to occur in 2018, at a total cost of $1.6 billion (NOAA 2020a).

Figure 5. Property Damage in Central/Eastern Tornadoes/Severe Weather, July 2018



Source: NOAA 2019a.

In only a matter of minutes, homes, businesses, government buildings, and infrastructure were damaged or destroyed by the tornadoes. Iowa suffered the most extensive impact, with $320.4

million in property damage. Georgia experienced $12.4 million in property damage, and Kentucky, $1.1 million. In total, the severe weather system resulted in over $336.0 million in property damage, with FEMA providing $4.0 million in public assistance.

Not every affected state reported property damage from the severe weather that July, yet all 14 states reported crop losses, the vast majority of which appear to have been caused by excess moisture and precipitation pummeling the fields. In all, over $146 million in crop indemnities were reported (see

Table 5). North Carolina's tobacco farmers and other producers reported over $31 million in losses, while the toll on Iowa's corn, soybean, and other farmers exceeded $30 million. Kansas farmers reported over $18 million in lost crops, most of which was attributed to hail. Overall, corn was the crop most affected, at $42.0 million in USDA-reported crop indemnities. The soybean and tobacco industries also suffered heavy losses (see Figure 6).

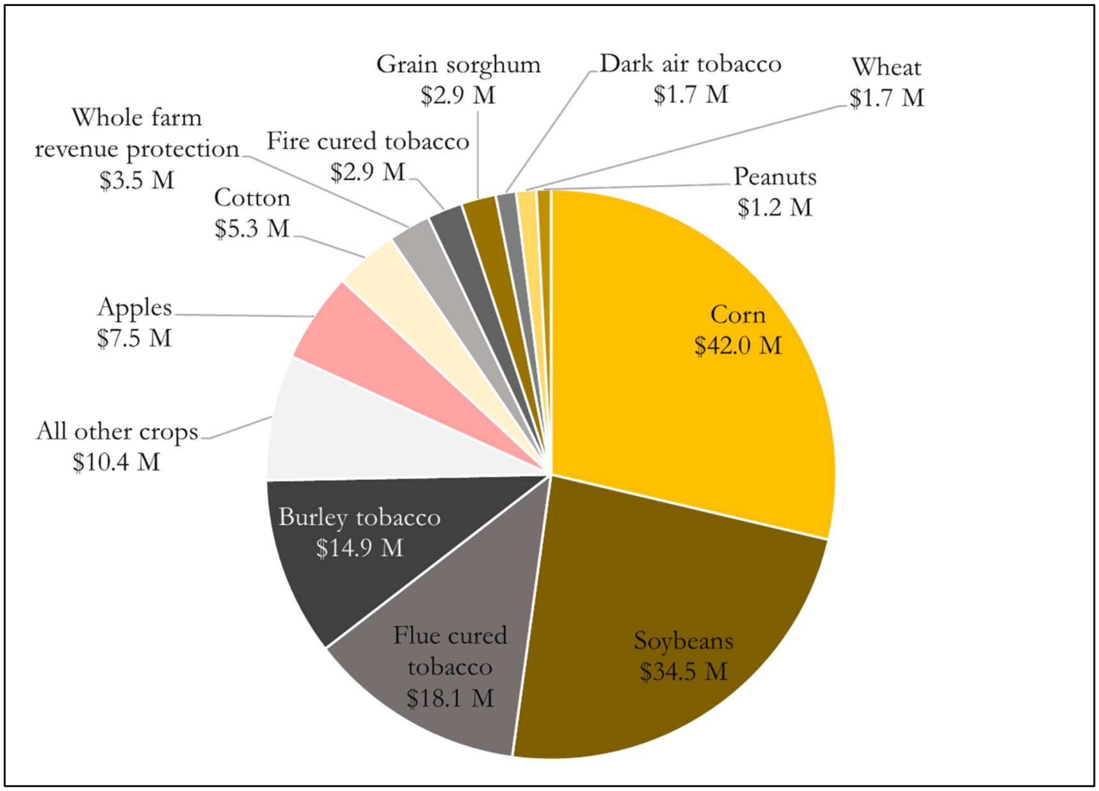
Table 5. Cost of Central/Eastern Tornadoes/Severe Weather to Affected States, July 2018

State	USDA-reported Crop Indemnities*	Types of Crops
Alabama	$728,000	Cotton, soybeans, peanuts, corn, wheat, other
Arkansas	$2,599,000	Soybeans, rice, tomatoes, corn grain sorghum, wheat, oats, other
Georgia	$5,564,000	Cotton, peanuts, corn, tobacco, soybeans, other
Iowa	$30,225,000	Corn, soybeans, grain sorghum, oats, forage product, other
Illinois	$3,996,000	Soybeans, corn, wheat, grain sorghum, oats, other
Indiana	$5,290,000	Soybeans, corn, wheat, popcorn, tobacco, grain sorghum, other
Kansas	$18,445,000	Corn, grain sorghum, soybeans, wheat, cotton, other
Kentucky	$22,448,000	Tobacco, soybeans, corn, wheat, other
Maryland	$4,102,000	Corn, soybeans, beans, cucumbers tomatoes, wheat, grain sorghum, potatoes, apples, other
Missouri	$3,378,000	Tobacco, soybeans, corn, wheat, grain sorghum, oats, other
North Carolina	$31,697,000	Tobacco, soybeans, corn, cotton, apples, potatoes, peanuts, wheat, sage, grain sorghum, other

Pennsylvania	$10,552,000	Apples, corn, soybeans, wheat, peaches, potatoes, oats, grapes, grain sorghum, barley, other
South Carolina	$1,209,000	Tobacco, cotton, soybeans, corn, peanuts, wheat, other
Virginia	$6,322,000	Apples, tobacco, soybeans, potatoes, corn, cotton, peanuts, wheat, other
TOTAL	**$146,555,000**	

Sources: USDA 2018. *USDA numbers are as reported (in 2018 dollars) and are rounded to the nearest thousand; Indemnity amounts are total losses reported in July 2018 by crop insurance policyholders.

Figure 6. Crop Loss in Central/Eastern Tornadoes/Severe Weather, July 2018



Source: USDA 2018.

Iowa Economy

No other state experienced worse damage from the July 2018 central and eastern tornadoes and severe weather than Iowa. Dozens of tornadoes from the severe weather system swept through the central part of the state, causing devastation in several counties. Among the five counties with the highest NOAA-reported property damage, Marshall County had losses of $200 million. In nearby Marion County, this number was $120 million (see Table 6).

Table 6. Property Damage in Tornadoes/Severe Weather, Selected IA Counties, Jul 2018

County	NOAA-reported Property Damage
Marshall	$200,000,000
Marion	$120,000,000
Polk	$287,000
Mahaska	$80,000
Jasper	$8,000

Source: NOAA 2019a.

In Marion County, Vermeer, a construction and agricultural equipment manufacturer on the outskirts of Pella, was slammed by an EF-5 tornado—the highest level of the rating system. Vermeer employs 2,700 people at its Pella plant. According to Vermeer CEO Jason Andringa, several buildings sustained structural damage. The company's management facility was "a total loss" (Gruber-Miller and Hardy 2018).

In several additional counties in Iowa, farms suffered severe crop damage. Farmers faced million-dollar losses in corn, soybeans, oats, and other crops. USDA-reported crop indemnities in Clay County and Kossuth County each surpassed $2 million (see Table 7).

Table 7. Crop Losses in Tornadoes/Severe Weather, Selected IA Counties, Jul 2018

County	USDA-reported Crop Indemnities **	Crop Type(s)
Clay	$2,175,000	Corn, soybeans, oats
Kossuth	$2,005,000	Corn, soybeans, oats, other
Palo Alto	$1,593,000	Corn, soybeans
Pocahontas	$1,563,000	Corn, soybeans
Hancock	$1,258,000	Corn, soybeans

Source: USDA 2018. *USDA numbers as reported (in 2018 dollars) and are rounded to the nearest thousand.
**Reported causes of crop indemnities include cold, wet weather, excess moisture/precipitation, flood, and hail.

In the aftermath of the severe storms, Iowa has faced the dual challenge of limited recovery funding and disbursement delays. Although approval was given for public assistance—making federal funds available to local governments and nonprofits—FEMA denied Iowa Governor Kim

Reynolds' appeal for individual assistance. FEMA officials told the governor's office that after a review of the twisters' aftermath, it "reaffirmed its finding that the effects were not severe enough for individual assistance" (Davis 2018). Nearly a year later, in March 2019, the Iowa Economic Development Authority and Iowa Finance Authority stepped in with a combined $2 million in funding to aid ongoing recovery efforts (Jordan-Heintz 2019).

Marshall County

Extreme weather events can wreak havoc on local economies, with an especially dramatic impact on local businesses. Although companies of all sizes can suffer tremendous losses, it is easy to imagine the extra difficulty small and medium-size businesses face in recovering from a disaster. For many, structural damage, and the likelihood of having to close for days, weeks, or months afterward, can mean losing substantial revenue, staff, and perhaps having to shutter permanently--all of which can have extensive effects on the local economy.

Such was the case in Marshall County, where the July 2018 tornadoes hit with a vengeance. After cutting wide paths of destruction across nearby crop fields, tornadoes plowed through the central business district of Marshalltown, damaging and destroying structures (NOAA n.d.-c). The town suffered catastrophic damage, including "vehicles missing, vehicles overturned, tops of buildings gone, trees down," along with live power lines and gas mains causing hazardous conditions for residents (Cappucci and Samenow 2018). Local heating, ventilation, and air conditioning (HVAC) manufacturing facility Lennox—one of Marshalltown's largest employers, with about 1,400 employees—saw its roof ripped away (Clayworth 2018).

> "…Workers at the [JBS] meatpacking plant lost pay for any days the plant was shut down because the tornado was an 'act of God' and not covered under the union contract." (Gaarder 2018).
> *--Roger Kail, President of the United Food and Commercial Workers Local 1149*

The disaster was particularly harmful to small businesses that lacked adequate property insurance to cover their losses and rebuild or had inadequate business disruption insurance to help stay afloat after temporarily closing their doors. Many small business owners in Marshalltown were concerned that the collapse of their businesses would leave many more people in the town unemployed (Dresser 2018).

> According to a Federal Reserve Bank study, few small businesses have insurance to cover having to close during and after a disaster. Of affected firms, only 17% had business disruption insurance (US Federal Reserve Banks 2017).

As is often the case with disasters, housing was also dramatically affected, particularly for Marshalltown's low-income and vulnerable populations. A post-tornado housing market assessment found that the tornado disproportionately affected lower-income housing in the Marshalltown Market Area, where over 90 percent of all damaged properties were valued under

$100,000 (Riley and Scepaniak 2018). The assessment further estimated that, due to the tornadoes, more than 70 elderly homeowning households were forced to convert to rental housing. As the chairman of the Iowa Disaster Human Resource Council, Greg Smith, noted, “It is not unusual for the poorest of the community to become poorer after a disaster” (Dresser 2018).

IV. Flooding

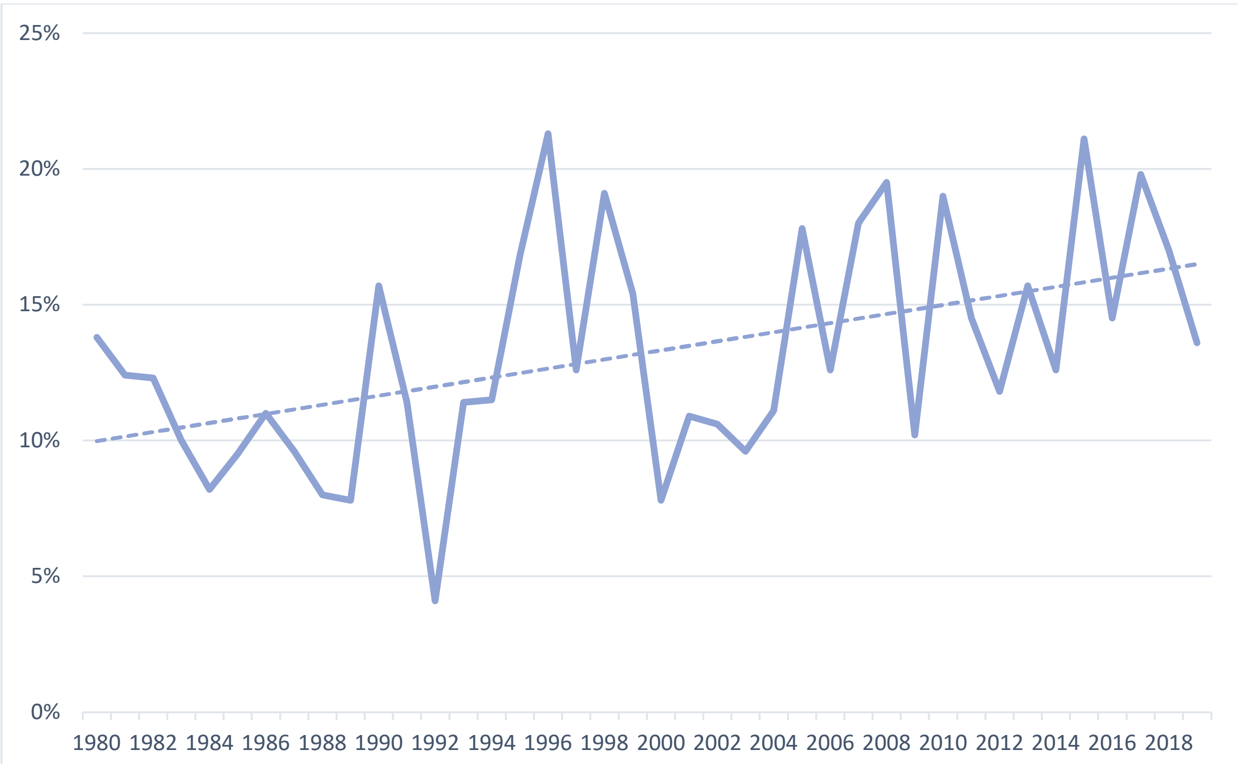
- Total CPI-adjusted direct cost, in the 1980s, of billion-dollar inland flooding disasters not associated with hurricanes: **$10.6 billion**
- Total CPI-adjusted direct cost of such disasters in the 2010s: **$60.5 billion**
- In the five North Carolina counties worst hit by Hurricane Matthew in 2016, share of business property damage that was in inland, not coastal counties: **92 percent**

Whenever a great volume of water overwhelms the land's capacity to drain (either via natural or built drainage systems), flooding results. It can be caused by an extreme rainfall event, rainfall on already-saturated land or baked-dry land, combined rainfall and snowmelt, infrastructure failure, or some combination. About three-quarters of all presidential disaster declarations involve flooding (NWS n.d.-a). Although hurricane-related, coastal floods seem to capture more headlines, inland flood events can be just as disastrous. The most powerful inland floods can sweep away cars, roll boulders, rip out trees, and trigger mudslides. Even moderate flooding can cause loss of life and damage or destroy homes, businesses, crops, and infrastructure. In addition, many US cities have combined sewer systems—in which stormwater and wastewater are mixed, treated, and released—so a flood can also overwhelm utilities and send stormwater and raw sewage straight into the environment, threatening human health and fisheries (Solecki and Rosenzweig 2012).

Evidence is mounting that human-caused climate change has led to a global increase in the frequency and intensity of heavy precipitation events (IPCC 2018), which are a major cause of inland flooding. Several attribution studies have found that specific heavy rainfall events that caused extreme flooding were likelier to occur due to human influence on the climate: downpours in Louisiana and Europe in 2016, each of which caused disastrous flooding, were found to be at least 40% likelier due to climate change (WWA 2016a; 2016b). Given that there is more evaporation in a warmer world, the atmosphere contains more moisture. The excess moisture can lead to more precipitation falling during a rainfall event. Since the late 1950s, every region of the contiguous United States has seen an increase in the amount of rain falling in the most extreme events, with the highest increase, 55%, found in the Northeast (USGCRP 2017c). Unlike moderate rainfall, which sustains crops and recharges water supplies, an extreme rainstorm causes crop damage, flooding and soil erosion.

Across the contiguous United States, the overall increase in the frequency and intensity of the heaviest non-tropical precipitation events—meaning those not associated with hurricanes—is shown in Figure 7. One-day precipitation extremes are defined as those in the highest tenth percentile, typically causing severe flooding. This measure indicates an important change in the pattern and timing of precipitation, i.e., that severe events are affecting an increasing percentage of the United States. By this indicator, three of the top five years recorded were in 2015, when 21 percent of the country had such 1-day extremes, in 2017 (19 percent), and 2010 (19 percent) (NCEI 2020b)

Figure 7. Share of Contiguous US That Had 1-Day Precipitation Extremes, 1980-2018

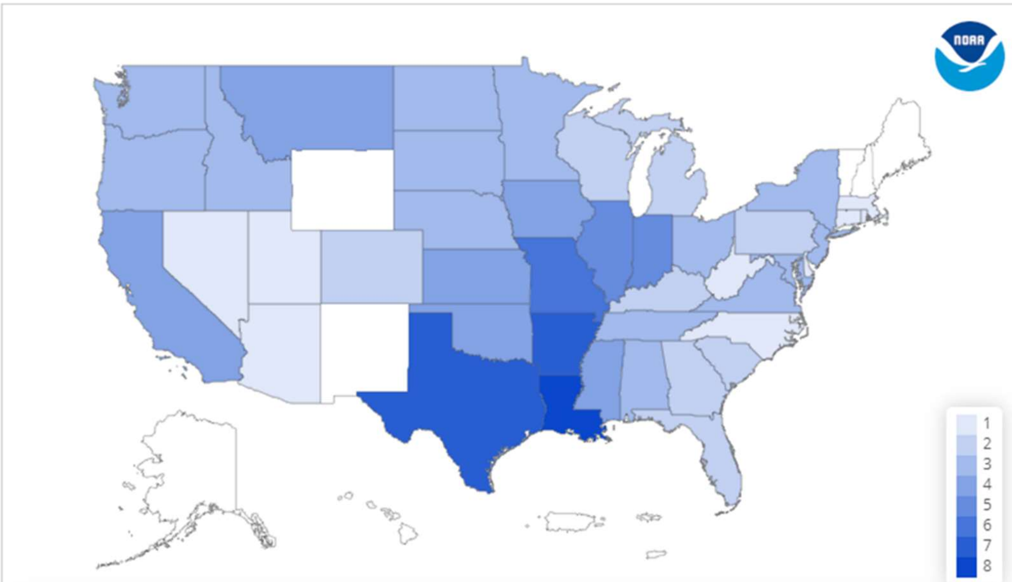


Source: NCEI 2020b. *1-day extreme is defined as the highest tenth percentile of 1-day precipitation events.

NOAA estimates that since 1980, billion-dollar flooding disasters—only those not associated with hurricanes—have cost the United States a CPI-adjusted total of $126.5 billion in direct costs. The decade of the 1980s saw a total of three such disasters, while the decade of the 2010s saw 18 (NOAA 2020a). The NOAA-estimated, CPI-adjusted direct cost of this past decade's billion-dollar floods is $60.5 billion, or nearly six times that in the 1980s. Most recently, in March of 2019, flooding in the Midwest inundated millions of agricultural acres, along with many towns and cities. It cost an estimated $10.8 billion in direct damage, making it one of the costliest US inland floods on record (NOAA 2020a).

Every state is vulnerable to at least one type of flood—whether from coastal, riverine, urban, or flash flooding—and similarly, non-tropical storm flooding of billion-dollar magnitudes has spared very few states. Since 1980, the only states not involved in such disasters were Wyoming, New Mexico, and three northeastern states that do experience frequent flooding, just not billion-dollar floods; these are Vermont, New Hampshire, and Maine (see Figure 8). The most-often-hit states in the 1980-2019 period were Louisiana and Texas, which were involved in eight and seven different billion-dollar floods, respectively.

Figure 8. Number of US Billion-Dollar Non-Tropical Flooding Disasters, 1980-2018



Source: NOAA 2019. Note: this map refers to flooding resulting from rainfall other than that directly associated with tropical cyclones (hurricanes). Billion-dollar designation is based on CPI-Adjusted costs (2019 dollars).

As the world continues to warm, scientists anticipate continued increases in heavy precipitation events, suggesting a likely increase in flood disasters—with significant variations geographically (IPCC 2013b). By the end of the century, the area of the one-percent-annual-chance floodplain could increase by about 30 percent, with the most extensive changes being in the Northeast and the Great Lakes regions (USGCRP 2017a).

North Carolina Inland Flooding After Hurricanes, 2016 and 2018

> "The ocean can receive a lot of water. It's the river areas where the confined river basin backs up the water, and it just can't flow out fast enough"
> --*Spencer Roger, coastal construction and erosion specialist with North Carolina State University's Sea Grant*

North Carolina's experience serves as a useful example of disastrous inland flooding in recent years, even though it does not fit neatly into the NOAA billion-dollar disaster framework used throughout this report. Since the North Carolina floods we describe below were associated with tropical cyclones (hurricanes), they could logically be included in the "Hurricanes" chapter. Yet we include them here, in the chapter on inland flooding, for a simple reason: although media reports and disaster recovery efforts after a hurricane tend to focus primarily on coastal communities, the hurricanes in question also caused catastrophic harm to North Carolina communities that are not exactly on the coast, and this harm is worth documenting in detail.

In early October 2016, Hurricane Matthew struck North Carolina as a Category 1 storm. With the ground already saturated from heavy rains in September, the hurricane brought parts of the state upwards of 17 inches of rain in a single day (Harlan and Fritz 2016). Most rainfall came within a 12-hour period. Record-setting river flooding occurred along the Neuse, Cape Fear, Tar, and Lumber Rivers (NOAA 2020b).

Even as the storm turned eastward toward the Atlantic Ocean on October 9, river flooding did not stop. Rivers continued to rise, taking days to reach their crests, and weeks to recede back below flood stage.

Less than two years after Hurricane Matthew, North Carolina rivers were again overwhelmed by the extreme rainfall that accompanied slow-moving Hurricane Florence. As the powerful storm surge and historic rainfalls of 20 to 25 inches ravaged coastal counties, isolated areas of inland counties, including Bladen and Robeson Counties, had up to 35 inches. Heavy rainfall continued even after storm surges subsided, dragging the event out over five days as the storm crawled inland, sometimes lingering in nearly the same spot for days. In total, Hurricane Florence dumped about nine trillion gallons of water on North Carolina (Halverson 2018). Epic river flooding made dozens of main highways impassible. Rivers remained in flood stage for weeks after the storm had passed (NOAA 2020b).

Hurricanes Matthew and Florence each took a heavy toll on North Carolina communities, residents, and businesses. Overall, Hurricane Matthew was responsible for an estimated $4.8 billion in damage to homes, businesses, public facilities, roads, and agriculture and caused damages to over 19,000 businesses (Cooper 2017). A state assessment of Hurricane Florence found that it caused water damage to approximately 3,800 businesses and wind damage to another 23,000 businesses; it further estimated that businesses and nonprofits had suffered $5.7 billion in damages (Cooper 2018).

Losses reported by the SBA, USDA, and NOAA confirm the repeated damage to small businesses and the agriculture sector in North Carolina. Between the two events, the SBA verified a total of $886.0 million in damages to business real estate and content such as inventory and machines, as shown in Table 8. Crop indemnities reported to the USDA came to nearly $192.1 million for both events combined, while combined property damage topped $2.8 billion.

Table 8. Reported Losses from Hurricanes Matthew and Florence in NC, 2016 and 2018

Damage Type	Hurricane Matthew*	Hurricane Florence**	Total
SBA-verified Business Losses	$246,134,000	$619,877,000	**$886,011,000**
USDA-reported Crop Indemnities	$45,821,000	$146,343,000	**$192,164,000**
NOAA-reported Property Damage	$860,201,000	$1,973,940,000	**$2,834,141,000**

Sources: NOAA 2019a; SBA 2018; 2019; USDA 2016; 2018. *Reported figures have been converted from 2016 to 2019 dollars.
** Reported figures have been converted from 2018 to 2019 dollars.

Robeson County

On its best day, the 115-mile-long Lumber River that cuts through Robeson County, NC offers enjoyments such as canoeing, fishing and picnicking. But twice in less than 24 months, the river gave towns in the flat coastal plains of south-central North Carolina a vastly different experience. Hurricane Matthew dealt the initial blow in October 2016. Hurricane Florence added insult to injury in September 2018.

In Robeson County, towns continue to struggle to make up for the loss of manufacturing jobs (Harlan and Fritz 2016). The county has a poverty rate of 29.2% and a median household income of $32,407, as compared to the North Carolina poverty rate of 16.1% and median income of $53,855 (Data USA 2017). It is a diverse county where 36% of the population is black, and 12% is American Indian (Keyssar and Brown 2019)

Residents of Robeson County prepared for a storm, but they did not expect nearly as much rain from Hurricane Matthew as they received (Bidgood and Blinder 2016).

> "What we're talking about, particularly in eastern Carolina, are some of the poorest communities in the country—black and white, who already had economic challenges before something like this…When a flood like this hits, the pain of it is exacerbated by the poverty"
>
> *-- Rev. William Barber, President, North Carolina NAACP*

Matthew arrived on October 9, 2016 after local heavy rains at the beginning of the month had already raised the Lumber River to its flood stage of 13 feet (NIST 2018). When Matthew added its onslaught, the river reached a record 24 feet. This exceeded predictions from a week earlier by almost five feet, surprising residents as forecasts changed "truly as [the event] was happening," according to Weather Service hydrologist, Lara Pagano (Harlan and Fritz 2016). It took until October 23 for the river to drop back below flood level (NIST 2018).

Of the top five North Carolina counties to experience losses to businesses from Hurricane Matthew, four are located inland. Damage in inland counties accounts for 92% of the total $175.5 million in business real estate lost by the top five affected counties, and 93% of the total $22.1 million in business content lost by the top five, as shown in Table 9. Robeson County had the highest SBA-verified losses to businesses of any North Carolina county after Hurricane Matthew: a total of $121.3 million in combined real estate and content losses, accounting for more than 50% of all SBA reported losses in North Carolina (SBA 2016).

Table 9. Top Five NC Counties with SBA-Verified Losses from Hurricane Matthew, 2016

County	SBA-verified Real-estate Loss*	SBA-verified Content Loss**
Robeson	$108,463,000	$12,801,000
Cumberland	$24,249,000	$3,994,000
Wayne	$19,063,000	$1,912,000
Dare	$12,427,000	$1,533,000
Columbus	$11,315,000	$1,811,000
Top Five Total	**$175,517,000**	**$22,051,000**

Source: SBA 2016. *Real estate losses refer to damage to property consisting of land or buildings, and other immovable business property. **Content losses include items such as inventory, machine, equipment, and leasehold improvements. Figures are reported in 2016 dollars.

In Hurricane Florence it was, as expected, the coastal areas of North Carolina that were particularly slammed—yet river flooding in Craven and Robeson counties also caused substantial damage. The 10 counties with highest SBA-verified losses are shown in Table 10. These ten counties incurred a total of $524.9 million in real estate losses, and 91% of this total occurred in coastal counties. Similarly, the 10 counties suffered a total of $39.9 million in damage to business content, of which 90% was in coastal counties. The highest business losses from Hurricane Florence were along the coast in New Hanover County, where Wilmington is located. Extensive losses were also felt in Craven County—mostly in New Bern, where the Trent and Neuse Rivers meet. Businesses in inland Robeson County were again damaged by Florence, after already having had a total of $121.3 million in verified business losses from Hurricane Matthew.

Table 10. Top 10 NC Counties with SBA-Verified Losses from Hurricane Florence, 2018

County	SBA-verified Real estate Loss*	SBA-verified Content Loss**
New Hanover	$167,916,000	$5,981,000
Onslow	$90,586,000	$4,145,000
Craven	$79,606,000	$6,672,000
Pender	$75,253,000	$8,290,000
Carteret	$30,061,000	$6,742,000
Pamlico	$27,367,000	$2,379,000
Duplin	$21,259,000	$1,953,000
Cumberland	$16,269,000	$841,000
Brunswick	$8,258,000	$1,816,000
Robeson	$8,365,000	$1,102,000
Top 10 Total	**$524,940,000**	**$39,921,000**

Source: SBA 2018. *Real estate losses refer to damage to property consisting of land or buildings, and other immovable business property. Figures are reported in 2018 dollars. **Content losses include items such as inventory, machine, equipment and leasehold improvements. Figures are reported in 2018 dollars.

Robeson County: Lumberton

Business losses from Hurricane Matthew were exceptionally high in Lumberton, the seat of Robeson County. Heavy rainfall from the Hurricane overwhelmed Lumberton's levees and drainage systems (Harlan and Fritz 2016). A previously identified but unaddressed gap in the levee system allowed the river to flow over the road and railway tracks that run under I-95 and into the levee-protected areas (Keyssar and Brown 2019; Harlan and Fritz 2016). Lumberton alone experienced almost 40% of the state's SBA-reported business losses.

Of the seven businesses along a main Lumberton corridor that were interviewed after the 2016 flooding, all seven reported losing power and having some contents damaged or lost. A propane distributor who experienced a flooding depth of four feet moved locations. Other businesses, including a bank, a retail store, a gas station, a furniture store and a liquor store, sustained floodwaters ranging from one to 24 inches. They took multiple weeks to re-open. Business owners expressed that their financial burdens were large relative to their incomes and felt that government resources were lacking (NIST 2018).

As a result of the 2016 flooding, schools and grocery stores were shuttered and the whole town lacked running water (Harlan and Fritz 2016). All 42 Robeson County schools serving 24,000 students were closed for three weeks due to flooded buildings, road closures, power outages, damaged water systems, kitchens contaminated from rotting food, and displaced students and staff (NIST 2018).

The Lumberton flooding seemed to have disparate impacts on minority and low-income residents. Minority households were found to have a much higher likelihood of residing in Lumberton's flood zones (NIST 2018), and indeed, while the low-elevation, largely African American section of town south of the Lumber River stood in feet of water, the predominantly white area was largely unharmed (Harlan and Fritz 2016; NIST 2018). In a city where 48% of American Indians and 45% of African Americans live below the poverty line—as opposed to 15.5% of whites (NIST 2018)—it is likely that many of those who were most severely affected were low-income households.

Columbus County: Fair Bluff

Meanwhile, 25 miles up the road, the Main Street in Fair Bluff—a town of 600 people—sat in four feet of water. Most buildings were left unusable after Matthew's waters lingered for up to two weeks. Less than two years later, waters from Florence covered virtually the same areas, sometimes reaching as much as four inches higher (Wagner 2019).

The estimated median income in Fair Bluff is even lower than in the county, at $27,898 with one in every five households living below the poverty line (Wagner 2019). Brenden Jones, a current State Representative and owner of a funeral home in Fair Bluff that was spared from flood damage noted, "Because it's so small, income levels are so low here, it's going to be hard for them to justify putting the money back in to reopen their businesses" (Bidgood and Blinder 2016).

Today if you visit Main Street in Fair Bluff, where once you would find a quaint commercial district with a beauty salon, doctor's office, and drugstore, now all you will find is a post office—the only operation that was willing to risk re-opening after the repeated flooding nightmare. Michael Green, who owned MikeMike's Computers on Main Street, reported losing about $50,000 worth of computers and office supplies after Matthew. He now operates out of a gas station kiosk (Wagner 2019).

Fair Bluff's Mayor Al Hammond and the part-time town manager Al Leonard are grappling with the fact that downtown Fair Bluff will never return to Main Street. They are working on a plan to annex an area of land that did not flood in Florence or Matthew. In July 2019, Leonard summarized, "Right now, we don't have any match money, and we don't have a grant. All we've got is a plan" (Wagner 2019).

Impacts on Agriculture

In addition to devastating impacts on businesses, flooding from Hurricanes Matthew and Florence also caused widespread damage to the agricultural sector. The top three crops damaged in both events were flue-cured tobacco, soybeans, and cotton. Together, the USDA-reported damage to these three crops from the two disasters was nearly $163 million, as shown in Table 11. In Goldsboro, in east-central NC, soybean crops were said to be under four feet of water (Maher and Kesling 2018).

Table 11: Top Crop Losses in North Carolina, October 2016 and September 2018

Crop Type	USDA-reported Crop Losses* Hurricane Matthew (October 2016)	USDA-reported Crop Losses * Hurricane Florence (September 2018)	Total
Flue Cured Tobacco	$5,185,000	$83,642,000	**$88,827,000**
Soybeans	$12,184,000	$32,340,000	**$44,524,000**
Cotton	$16,001,000	$17,492,000	**$33,493,000**
Top 3 Total	**$32,584,000**	**$130,353,000**	**$162,937,000**

Source: USDA 2016; 2018. * Figures have been converted to 2019 dollars. Causes of crop damage include "Excess Moisture/Precipitation/Rain," "Hurricane/Tropical Depression," "Flood," and "Wind/Excess Wind."

Agricultural producers also suffered the loss of livestock and poultry. It was estimated that more than 5,500 hogs and 3.4 million chickens and turkeys were killed during Hurricane Florence (Pierre-Louis 2020).

Flooding near animal operations not only poses an economic risk to livestock owners, but also a health risk to the communities located near animal operations—who are disproportionately people of color. During a flooding event, neighboring residents are subject to harmful pollutants typically generated by swine and poultry operations as they flood into nearby waterways and the surrounding communities. Communities located in the same zip code as swine concentrated animal feeding operations (CAFOs) are shown to have higher than average mortality rates, which cannot be explained by socioeconomic, demographic, behavioral, or access-to-care co-factors (Kravchenko et al. 2018). A 2002 study after Hurricane Floyd found that African Americans were more likely than their white counterparts to live near flooded CAFOs (Wing, Freedman, and Band 2002). Today, neighboring communities remain disproportionately people of color, with nearly 30% being African American, and 2.4% American Indian (Kravchenko et al. 2018). Swine CAFOs management practices have improved since Hurricane Floyd, but especially as rain events become more intense, the risk to public health remains. Having recently climbed to the top spot of North Carolina's agricultural economy (Stringham et al. 2018), poultry operations also pose a significant risk to nearby communities during flooding events (CBS News 2018).

V. Winter Storms

- Number of extreme US snowstorms in the latter half of the 20th century as compared to in the first half: **Double**
- Share of weather stations across the contiguous US that record increased winter precipitation that falls as rain instead of snow: **80%**
- Share of the water supply in drought-prone western states that comes from snowmelt: **as much as 75%**

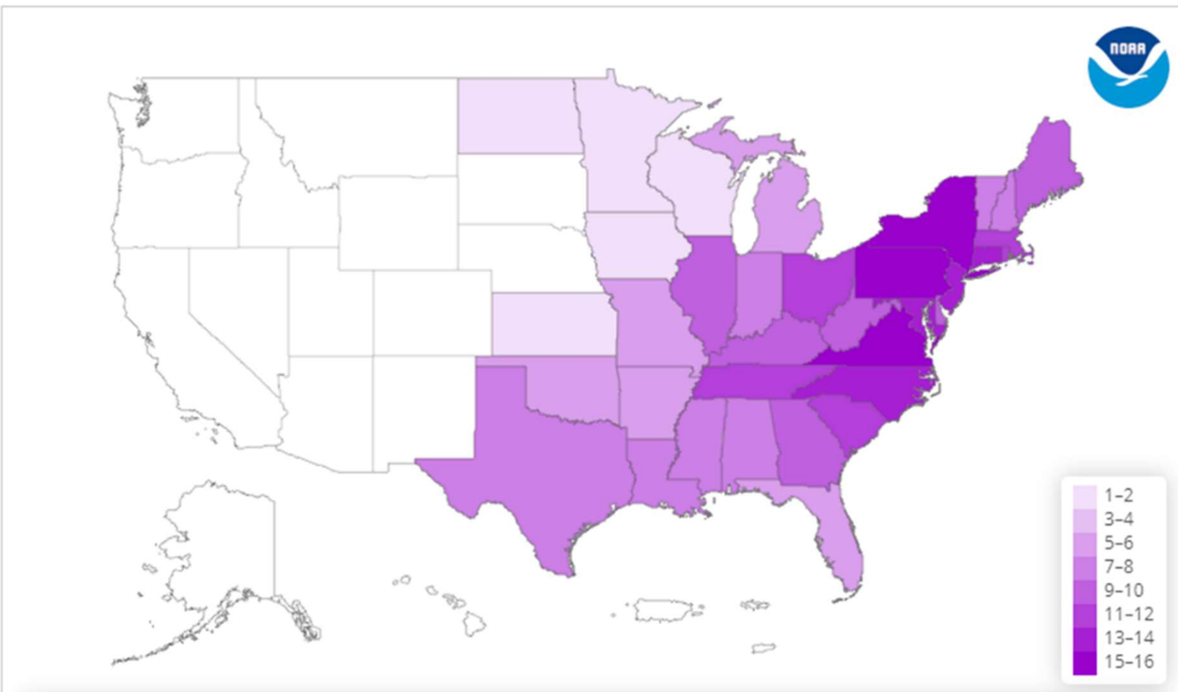
A winter storm can range from a heavy snow that falls over a few hours, to a blizzard with winds that whip the snow into blinding conditions and lasts for several days. Some, but not all, winter storms involve severe cold (NSSL n.d.). Often they are accompanied by ice forming on trees, power lines, and roads. They can do extensive damage with their high winds, heavy snow, and coastal erosion. Consequences often include stress on building roofs, clogged transportation routes, power outages, and agriculture and forestry losses.

Climate change mainly affects winter storms through more moisture in the atmosphere, such that if temperatures drop below freezing (less likely in a warming world but still occurring), there is the potential for more snow. Warmer-than-average ocean temperatures are also known to intensify storms, and scientists suggest that reductions in Arctic sea ice can change atmospheric patterns to favor winter storm development (NOAA n.d.-a). Further, meteorologists are observing the effects of sea-level rise on winter storms. Even absent a storm, more street flooding occurs during high tides all along the coast—so that when a storm hits in addition to the high tides, coastal flooding worsens, topping sea walls that had never been topped before (Samenow 2019). In the United States, winter storms have increased in frequency and intensity since 1950, with a slight shift in tracks toward the poles (USGCRP 2017c).

In our warming climate, even regular snowfall appears to be changing—and in ways that, even if leading to fewer billion-dollar winter storm disasters, are concerning because of our reliance on snowmelt for water supplies. Trends in snowfall and snowmelt depend on the region. Further, the seasonal period of snowfall is shrinking (Harvey 2019). This is partly due to a greater share of precipitation falling as rain rather than as snow. Between 1949 and 2015, nearly 80% of weather stations across the contiguous United States recorded an increase in winter precipitation that fell as rain instead of snow (NEEF n.d.). Along with shorter winters and earlier snowmelt, rising temperatures can also cause snow to melt faster, often running off quickly over still-frozen ground instead of gradually soaking in and recharging soil moisture. This is a particularly critical problem in the drought-prone western states, where as much as 75% of the water supply comes from snowmelt (USGS n.d.).

Meanwhile, the eastern two-thirds of the contiguous United States, by contrast, continues to be vulnerable to increasingly frequent snowstorms. According to NOAA, the United States saw about twice as many extreme US snowstorms in the latter half of the 20th century as in the first half (NOAA n.d.-a). Since the 1980s, billion-dollar winter storm disasters have been most frequent in New England, Pennsylvania and New York, regions that are vulnerable to Nor'easters (see Figure 9).

Figure 9. Number of US Billion-Dollar Winter Storm Disasters, 1980-2019



Source: NOAA 2020. Note: Billion-dollar designation is based on CPI-Adjusted costs (2019 dollars).

As for trends in cost, the billion-dollar winter storm disasters that continue to threaten the East and Northeast do not share the clear upward trend of hurricanes and severe storms. The costliest decade for winter storms was the 1990s, with a total of eight different billion-dollar winter storms, at an average of $3.18 billion per storm. The costliest of these was in 1993. That year, the "Storm of the Century" blanketed the entire East Coast, dumping as much as four feet of snow and causing tornadoes and hurricane-force winds. More than 10 million households lost power (NOAA 2020a). Still, severe winter storms have trended upward again in the current decade, and at considerable cost. Since 2011, the United States has experienced five different billion-dollar winter storms, including a $3.3 billion disaster in 2015, and two disasters totaling $3.4 billion in 2018 (NOAA 2020a).

Northeast Winter Storm, March 1-3, 2018

A powerful Nor'easter blew across several northeast US states from March 1-3, 2018, including Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Connecticut, Delaware, and Virginia. The storm originated as a stationery front over the Midwest on March 1, then moved eastward through to the Northeast, bringing snow, wind, and coastal flooding. The low-pressure center rapidly intensified on March 2, southeast of coastal New England where it produced hurricane force winds before moving out to sea by March 3 (NOAA 2019a).

> Nor'easters are fed by the difference in temperature between cold air from the polar jet stream over land, and warm air from the Gulf Stream over water. They typically develop within 100 miles of the east coast in latitudes between Georgia and New Jersey and reach maximum intensity over New England (NWS 2020).

The Nor'easter caused widespread damage throughout the entire northeast coast. Strong winds along the US East Coast downed trees and powerlines. Over two million people lost power throughout the eastern United States for over a week. The highest snowfall total from the storm, 40 inches, was reported in Richmondville, New York (R. Otto 2018). NOAA estimated the total CPI-adjusted, direct costs of the storm at $2.3 billion (NOAA 2019a).

VI. Freezes

- CPI-adjusted total direct cost of Southeast Freeze in March 2017: **$1.1 billion**
- South Carolina peaches wiped out: **80-85%**
- Georgia blueberries wiped out: **70-75%**
- North Carolina blueberries wiped out: **40-60%**

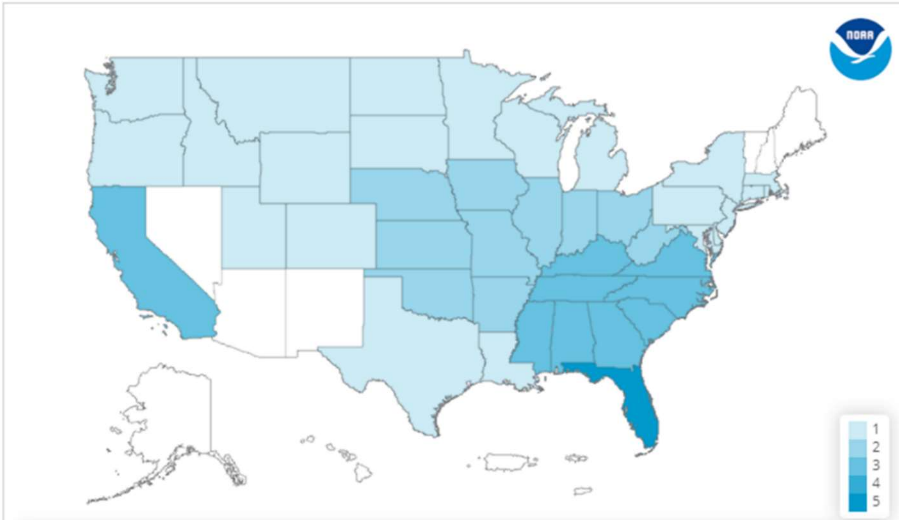
Winter freezes in a warming climate are a threat to regional agricultural economies. Although cold waves may be shorter and less frequent in a warming climate (Reidmiller et al. 2018; Climate Central 2019), the timing of present-day freezes has in some cases proven catastrophic, especially to farmers.

Crop losses from extreme cold temperatures are not just a question of where, but also of when. In a warming world where a “false spring” arrives early, plants and crops bloom prematurely (Samenow 2020). When a false spring arrives weeks before the last freeze of winter, the freeze can destroy crops (Ault et al. 2013). Even for crops that survive an untimely freeze, such an event can also hinder plant growth, seed production, and pollination (Reidmiller et al. 2018).

One reason for crop-damaging winter freezes is that extreme cold temperatures are reaching farther south. Given the continued warming in the Arctic—at two times the rate of the rest of the world —the jet stream has weakened and frigid polar air can occasionally penetrate farther south than normal (Francis, Vavrus, and Cohen 2017).

Although freezes may be the least frequent and least costly of the seven disaster categories addressed in this report, all but a handful of states are vulnerable to freeze disasters (see Figure 10). To date, states most at risk have been California, Florida, and other southeastern states. Although recent freezes in these areas have not always resulted in billion-dollar disasters, they have caused significant crop damage.

Figure 10. Number of US Billion-Dollar Freeze Disasters, 1980-2019



Source: NOAA 2020. Note: Billion-dollar designation is based on CPI-Adjusted costs (2019 dollars).

Even in a warming climate, crop-killing freezes continue to be a significant threat to agricultural producers. For example, at the time of this writing, in 2020, most locations in the US South and Southeast were experiencing one of their top 10 warmest winters on record. In some areas, spring arrived more than three weeks earlier than the 1981-2010 long-term trend (Samenow 2020), resulting in early blooming. This is an ongoing source of considerable concern for farmers who are at risk of having their blooms freeze.

In a warming world, researchers expect vulnerability to crop-damaging freezes to increase, with early onset of spring occurring (Barcikowska 2019) by mid-century, at nearly twice the rate previously observed (Labe, Ault, and Zurita-Milla 2017). Unless the last freeze date also changes at that same rate, the agricultural economy is at risk of large-scale losses (Reidmiller et al. 2018).

Southeast Freeze, March 14–16, 2017

In mid-March 2017, the Southeast was hit by the worst hard freeze faced by the region in 10 years (Crouch 2017). The unusually warm February and March led to crops blooming up to three weeks early, which set them up for ruin when an Arctic cold pressure system descended, resulting in widespread agricultural losses. The impacts of this freeze were felt across Georgia, South Carolina, and North Carolina, along with Tennessee, Alabama, Mississippi, Florida, Kentucky, and Virginia. Total estimated direct costs of the disaster, including insured and uninsured losses, were $1.1 billion (NOAA 2020a).

The greatest impact of the freeze was on crops in Georgia and the Carolinas, as shown in Table 12. Georgia had the highest USDA-reported crop damage, at $34.8 million, with the most severe impacts in the southeast part of the state. South Carolina and North Carolina each lost substantial crop values—$26.2 million and $24.0 million, respectively.

Table 12. Cost of Southeast Freeze to Affected States, March 2017

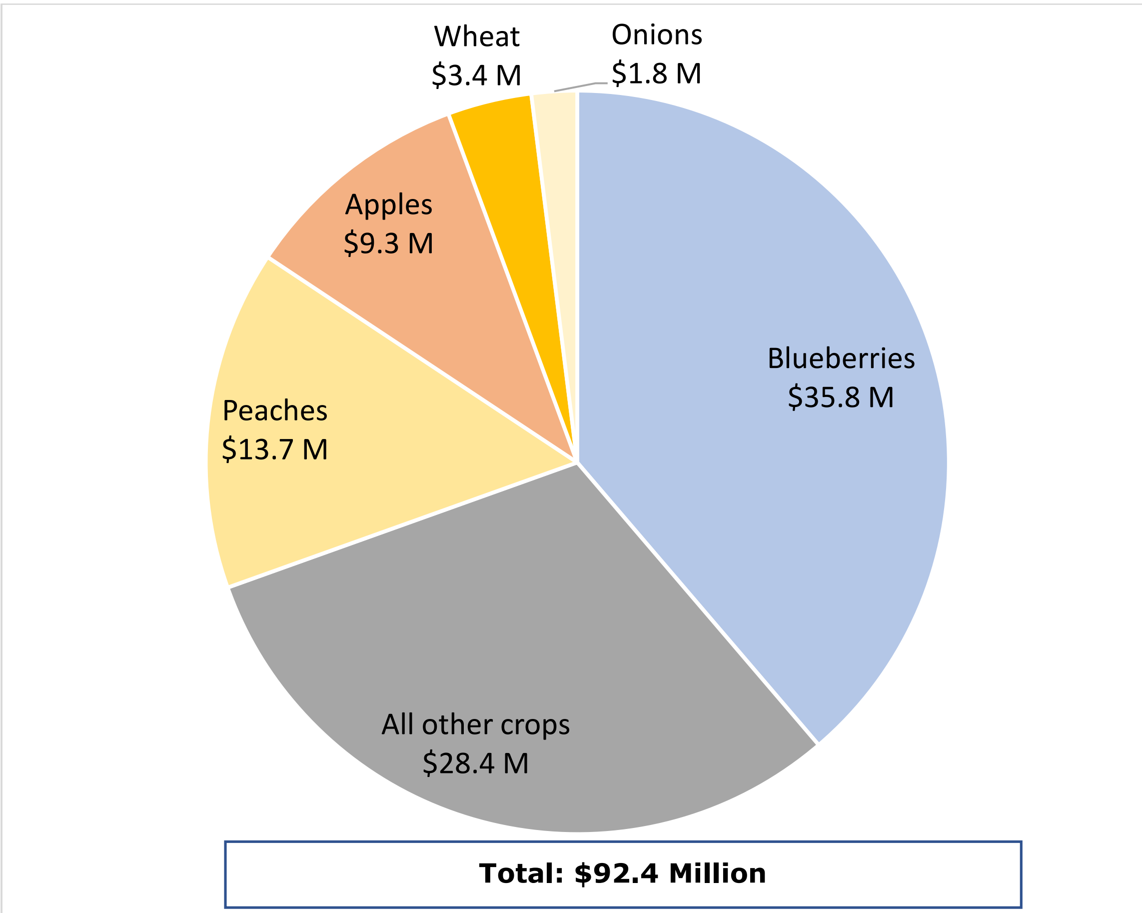
State	All USDA-reported crop indemnities*	% of USDA-reported crop indemnities that were Freeze-related**	Type of crop
Alabama	$352,000	60%	Peaches, corn, other
Florida	$2,609,000	53%	Potatoes, blueberries, cabbage, peppers, other
Georgia	$34,800,000	95%	Blueberries, wheat, peaches, pecans, other
Kentucky	$749,000	30%	Wheat
Mississippi	$825,000	9%	Unspecified
North Carolina	$24,030,000	98%	Blueberries, wheat, apples, peaches, oats, barley, other
South Carolina	$26,215,000	99%	Peaches, wheat, corn, other
Tennessee	$640,000	74%	Wheat, other
Virginia	$2,192,000	96%	Apples, wheat, peaches, barley, other
TOTAL	**$92,412,000**	**94%**	

Source: USDA 2017b. *USDA numbers are as reported in 2017 dollars and are rounded to the nearest thousand; Indemnity amounts are total losses reported by crop policyholders for the month of March 2017. **The crop indemnities included in the "Freeze-related" column were caused by either "Freeze" or "Frost" according to USDA.

Among the crops hardest hit by the Southeast freeze were peaches in South Carolina, one of the nation's top peach producers, second only to California. Of a total of $13.7 million in USDA-reported losses to crop policy holders for peaches across the Southeast (see Figure 11), South Carolina accounted for $9.5 million—or nearly 70% of the peach losses in the Southeast. However, this figure is almost certainly a large understatement, since experts estimated that 80-85% of the state's peach crop was wiped out. Such large-scale losses are a significant blow, given that the peach industry is normally estimated to have an overall direct and indirect economic impact in the state of approximately $300 million, providing jobs to 1,500 people (Carter 2017).

The March 2017 Southeast Freeze also dealt a blow to North Carolina blueberries. The state's blueberry industry is the nation's seventh largest, generating an estimated $72.1 million in income annually (Campbell n.d.). According to the North Carolina Department of Agriculture, the 2017 freeze wiped out between 40% and 60% of the state's blueberry crop (Carter 2017).

Figure 11. USDA-reported Crop Loss in SE Freeze, by Crop, March 2017

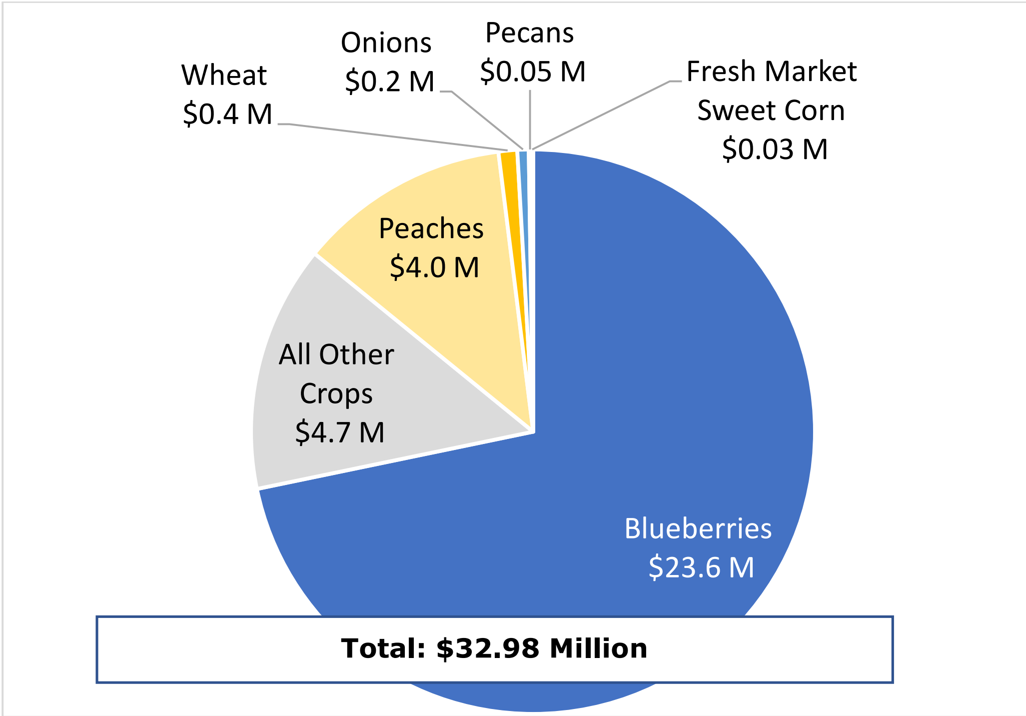


Source: USDA 2017b.

Georgia Economy

Among the states affected by the March 2017 freeze, Georgia suffered the most devastating crop losses. Temperatures in the mid-20s caused extensive damage to blueberry, wheat, apple, and peach crops, among others (NOAA 2019b). Georgia's USDA-reported crop losses to crop policy holders from the freeze reached nearly $33 million (see Figure 12). Of this, $23.6 million was for blueberries and $4.0 million for peaches. In a state where the agricultural sector is worth $74.9 billion and accounts for one in every seven jobs (Madel 2018), these losses had significant economic impact.

Figure 12. Georgia Crop Loss in Southeast Freeze, March 2017



Source: USDA 2017.

The losses to the blueberry industry were especially notable because in Georgia—traditionally known as the Peach State—blueberries are becoming increasingly crucial to the economy. Blueberries surpassed peaches as the state's top-value fruit as of 2012, and the gap between the two crops quickly widened. Today, Georgia is the nation's second largest blueberry producer, behind Washington state. The Southeast Freeze brought Georgia's projected 110-million-pound blueberry harvest down to as low as 30 million pounds (Carter 2017), a reduction of 70-75 percent.

Missing the four-month window for producing fresh blueberries made it difficult for Georgia to compete with blueberries imported from Mexico, which are already at an advantage from lower input, regulatory and labor costs (Mandel 2018). According to the Georgia Blueberry Commission, the swelling volume of blueberry imports from Mexico is becoming a serious issue, since the imported blueberries can sell for 30% to 40% below market price (Lawrence 2019).

The freeze abruptly derailed what had been expected to be another year of production growth. Instead, it was a severe setback to producers, especially those in the southeastern part of the state. As Georgia Agriculture Commissioner Gary Black told a reporter, "We saw blueberry fields that had the potential to be the biggest and best crop of Georgia's production history [where] you would now not be able to find enough blueberries that survived the cold to make one pie." (Collins 2017).

One year later, in 2018, Georgia farmers faced the same crisis all over again. In what is perhaps a sign of things to come in a warming world, early blossoms again emerged in a warm February, only to be struck by freezing temperatures in March. After losing at least 70% of their crop in 2017, Georgia farmers again suffered losses of 55% in 2018 (Sellers 2019). "The mood's not very good," said Renee Allen, University of Georgia Cooperative Extension agent. "I think the growers' spirits are down. We've been hit hard two years in a row." (Thompson 2018).

Bacon County

As an illustration of the economic impact a freeze disaster has on a heavily agriculture-dependent county, it is useful to look at Bacon County, in southeast Georgia. Bacon's main agricultural product is blueberries; hence the county's nickname, "Georgia's Blueberry Capital." With a population of 11,300 people, Bacon County has a median household income of $39,000, compared to the US median of $62,000. More than 23 percent of the county's population live below the poverty line, compared to the US rate of 13 percent (Data USA n.d.). When the 2017 freeze inflicted over $7 million in damage to Bacon County's blueberry crop (see Table 13), these losses were presumably felt keenly throughout the local economy.

Table 13. Crop Loss in 10 Georgia Counties Affected by the SE Freeze, Mar 2017

County	USDA-reported crop indemnities*	Crop types
Bacon	$7,127,000	Blueberries
Clinch	$3,536,000	Blueberries
Appling	$3,083,000	Blueberries, wheat
Taylor	$2,324,000	Unspecified
Ware	$2,020,000	Blueberries, other
Coffee	$1,689,000	Blueberries
Peach	$1,655,000	Peaches, wheat
Pierce	$1,624,000	Blueberries
Macon	$1,505,000	Peaches
Atkinson	$1,380,000	Blueberries

Source: USDA 2017. *USDA numbers are as reported in 2017 dollars and are rounded to the nearest thousand; Indemnity amounts are total losses reported by crop policyholders for the month of March 2017.

A signature event for Bacon County is its annual Georgia Blueberry Festival, which attracts visitors from all over the Southeast. Festival vendors depend heavily on the blueberry crop to draw visitors, who then also spend much-needed dollars in area hotels, restaurants, and entertainment venues. Because the early blueberry varieties had been almost completely wiped out by the 2017 freeze, festival organizers worried there may be no blueberries to sell at the festival, putting in jeopardy not just festival sales, but the additional festival-related spending that boosts the local economy. Fortunately, a handful of local growers were able to provide a few late variety berries, so that the festival could continue, albeit without the normal abundance.

Meanwhile, University of Georgia researchers began working with growers whose berries did develop that year, even if stunted or damaged by the freeze. Through this work, they hope to better understand how various freeze protection methods performed, in order to help growers endure killing freezes in the future (Cannady 2017).

VII. Drought

- Share of time, since 2000, that Nevada and Arizona have been in moderate or worse drought: **50%**
- In Northern Plains Drought of 2017, number of North Dakota counties that escaped moderate or worse drought status: **1 (out of a total of 53 counties)**
- Total North Dakota costs of that drought: **1-2% of GSP (Gross State Product)**

Compared with storms and floods, droughts are a quiet catastrophe, one that typically gets less public attention than other disasters, despite causing more damage than any other category except hurricanes. A drought is characterized as a period of relative dryness and low soil moisture, which depends on levels of rainfall and/or levels of evapotranspiration. It can last for a few weeks or several years. Human water management and land use also play a significant role in contributing to drought conditions, by diverting rivers, over-pumping groundwater, and creating impervious surfaces that cause rainwater to run off instead of replenishing soil moisture (Richter-Ryerson 2017).

NOAA treats the drought category differently from other disasters, counting the drought period in each year as a single event. By this measure, it is clear that billion-dollar-drought years have recently become much more common. Although the decade of the 1980s saw a total of only four years marked by billion-dollar droughts, that frequency has increased to every year from 2011 through 2018 (NOAA 2020a).

Climate change makes drought conditions likelier to occur. Higher temperatures increase evaporation, drying out soil. Circulation patterns are also changing in a warmer climate—deflecting storm systems away from precedential routes. Scientists have found that human-caused climate change has increased the chance of several specific droughts occurring—or made them more intense. These include the Texas Drought in 2011 (USGCRP 2017c), the East African Drought in 2011 (Lott, Christidis, and Stott 2013), the California Drought in 2013-2015 (Diffenbaugh, Swain, and Touma 2015), the Kenya Drought in 2016-2017 (Uhe et al. 2017), and the Cape Town Drought in 2018 (F. E. L. Otto et al. 2018).

The warming climate appears to have ushered in an additional phenomenon: the flash drought. Unlike hydrological droughts—in which groundwater, stream flow and reservoir levels can drop during several months or years—flash droughts can come on quickly. They can result from unusually warm temperatures, low humidity, sunny or windy conditions, and they can create drought conditions very quickly, with little warning. Flash droughts have had severe impacts on farmers in recent years, especially in the central United States in 2012, in the Southeast in 2016, and in the Northern High Plains in 2017 (NASA 2019).

Typical impacts of drought include crop losses, damage to rangelands, fish kills, forest dieback, pest outbreaks, and wildlife decline. The outdoor recreation industry suffers when water resources are low and when main attractions such as wildflowers or birds are killed or displaced. In cities, drought can increase groundwater pumping costs and shut down hydropower. As drying soil shifts, it can severely damage foundations and infrastructure, such as water mains.

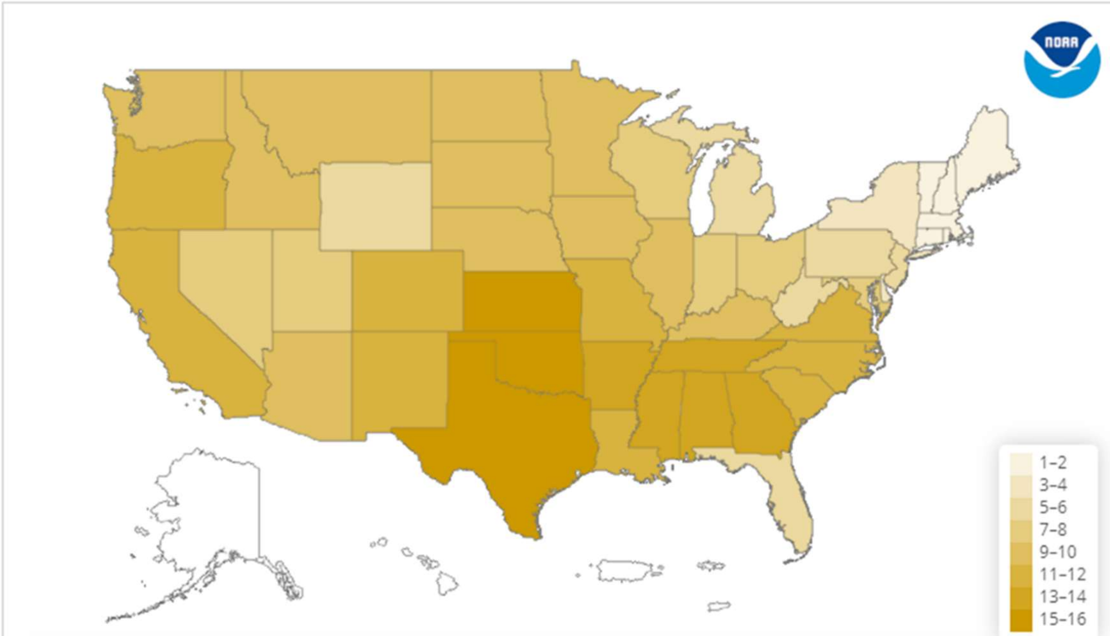
An indicator that helps identify developing drought conditions such as those that contribute to flash droughts is the Evaporative Stress Index (ESI), which measures water evaporating from land surface and plant leaves. Unfortunately, metrics other than those captured by the ESI are often used to determine eligibility for crop insurance—potentially limiting farmers' protection from flash droughts (NASA 2019).

Based on data in the NOAA Billion-Dollar Weather and Climate Disasters database, and using the CPI to adjust all costs to 2019 dollars, US droughts have cost a total of $249.7 billion since 1980 (NOAA 2020a). Since 2010, droughts have cost the nation on average $9 billion each year. These are direct costs, including insured and uninsured losses. Not included in these estimates, however, are related costs that are more difficult to quantify, such as health costs of anxiety from economic losses, conflicts over scarce water, heat strokes, and loss of human life (NCEI n.d.)

Recently, scientists have begun working to develop a broader framework to more accurately assess not just the obvious direct costs of droughts, but also the consequences to ecosystems and the crucial services they provide. Forest cover plays a role in improving air quality, for instance, and in filtering wastes and preventing soil erosion. As drought-stricken trees weaken and die, the ripple effects are felt across entire landscapes that depend on these critical ecosystem services (Crausbay and Ramirez 2017).

Drought can affect nearly every geography in the United States, but the costliest drought disasters since 1980 have been in the Southern Plains region, home to billions of dollars' worth of agriculture and livestock assets (see Figure 13). As for states that experience drought most often, the US Drought Monitor reports that since 2000, Nevada and Arizona have been in moderate or worse drought for at least 50% of the time. In several other states, exceptional drought—the top of the scale—occurs 14-20% of the time; these states are California, Colorado, New Mexico, Oklahoma, and Texas (Bolinger 2019).

Figure 13. Number of US Billion-Dollar Drought Disasters, 1980-2019



Source: NOAA 2020. Note: Billion-dollar designation is based on CPI-Adjusted costs (2019 dollars).

With continued rising temperatures, scientists anticipate longer dry periods in semi-arid regions of the midlatitudes and subtropics, such as the US Southwest (IPCC 2013a). Scientists suggest that increased evaporation due to rising temperatures may outpace increased precipitation, leading to more frequent and intense drought conditions across the continental United States (USGCRP 2017d). Researchers at NASA and Columbia University suggest the US Southwest could experience "megadroughts" that last over 30 years (Gray and Merzdorf 2019).

In our warming world, we can also expect increasingly volatile shifts between droughts and floods. An example is California, a state whose already-volatile climate will likely produce both more dry years and more wet years as human-caused climate change disrupts atmospheric circulation patterns over the eastern Pacific Ocean (Swain, Langenbrunner, and Neelin 2018). Although long-term average precipitation is not expected to change significantly, extremes will likely increase. The resulting sudden shifts between severe drought conditions and intense storms will pose daunting challenges to the state's efforts to store much-needed water on one hand, and to cope with flooding on the other (Boxall 2018).

Northern Plains Drought: March-December 2017

In 2017, Northern Plains farmers were taken by surprise by the swiftness and severity with which drought conditions spread throughout North Dakota, South Dakota, and Montana. A flash drought was caused by sudden and sustained high temperatures and exceedingly low precipitation. Soils dried rapidly and unexpectedly. The drought was nearly impossible to anticipate, given traditional methods of monitoring for potential drought by weighing snowpack with average seasonal temperatures. A senior climate scientist from the Union of Concerned Scientists commented, “The new normal is that now we have a warmer world; in times when you’re not getting your normal load of rain, things can go bad very quickly” (McLaughlin 2017).[4]

The drought was so intense that moisture levels in Montana and North Dakota reached lows rivalling the epic droughts of the 1930s and 1980s (NOAA 2019a). Severe drought conditions were found in all three Northern Plains states in early to mid-June, and by mid-July the drought in North Dakota and Montana was considered “exceptional”—the highest category on the drought scale.

Despite above-average rainfall in August (over five inches, as compared to the norm of around 1.75 inches), parts of the region remained in exceptional drought through September 2017 (Wynn 2017). More than 90% of North Dakota had abnormally dry conditions or worse through the end of the year (NDMC 2017). To add insult to injury, heavy rainfalls across the region in July and August caused flash flooding in areas that had not seen rain in some time, the water only rushing over the surface of parched soils.

Because of the intensity of the drought, the rain was not enough to salvage the grim outlook for agriculture. In this region of the country, a “severe” drought means that planting begins early and irrigation use increases. Hay is short, cattle sales are early (before the animals have gained sufficient weight to bring adequate prices), and water quality for agriculture operations is low. An “extreme” drought means significant row crop loss and increased cattle sales by producers unable to keep all their animals fed and healthy. “Exceptional drought” means even more significant row crop loss, falling market prices, and producers being forced to sell livestock herds.

All of which happened during the region’s 2017 drought season. Cattle sales were prompted by poor grazing conditions, feed shortages, and stock water shortages (NDMC 2020). Stockmen’s Livestock Exchange saw increased sales of cattle, weeks to months earlier than usual, because of limited feed supplies. The Exchange’s Managing Partner, Larry Schnell, reported selling “about 500 to 1,000 head each day more than what we normally would sell this time of year” (Schlecht 2017).

In each of the three states, crop losses were in the hundreds of millions. According to USDA, total crop indemnities reported by crop policy holders exceeded $861.2 million from March

[4] One result of the Northern Plains drought of 2017 was its contribution to Montana’s worst wildfire season in the state’s history (Puckett 2018). For more on this disaster, see Chapter VIII: Wildfires.

through December. North Dakota accounted for nearly half of these losses, at $404.9 million (see Table 14).

Table 14. Reported Crop Losses in Northern Plains Drought, Mar-Dec, 2017

State	USDA-reported Crop Loss*	Types of Crops
Montana	$220,324,000	Wheat, dry peas, forage product, barley, canola, corn, mustard, flax, safflower, forage seed, cherries, oats, sugar beets, other
North Dakota	$404,944,000	Wheat, corn, soybeans, canola, dry peas, barley, forage product, sunflowers, flax, oats, dry beans, other
South Dakota	$235,968,000	Corn, wheat, soybeans, forage product, sunflowers, oats, grain sorghum, dry peas, forage seeding, barley, millet, safflower, flax, dry beans, rye, other
TOTAL	**$861,236,000**	

Source: (USDA 2017). *USDA numbers are as reported (in 2017 dollars) and are rounded to the nearest thousand; Indemnity amounts are total losses reported from March 2017 through December 2017 by crop insurance policyholders. The crop indemnities included were caused by "Drought" or "Heat."

With all its devastating impacts on farmers and cattle producers, and its contribution to unprecedented wildfires, the Northern Plains flash drought struck some in the region as a sign of accelerating climate change. One Montana farmer, Rick Kirn, farms wheat in a small family farm in northeastern Montana, right at the epicenter of the disaster. Kirn confirmed that the drought hit him without any warning. "It's a total loss for me," he told a reporter. "There's nothing to harvest." He questioned whether his small farming operation had a future, given his inability to afford irrigation and an increasing vulnerability to climate. "This is absolutely the worst year I've ever seen." (McLaughlin 2017).

North Dakota Economy

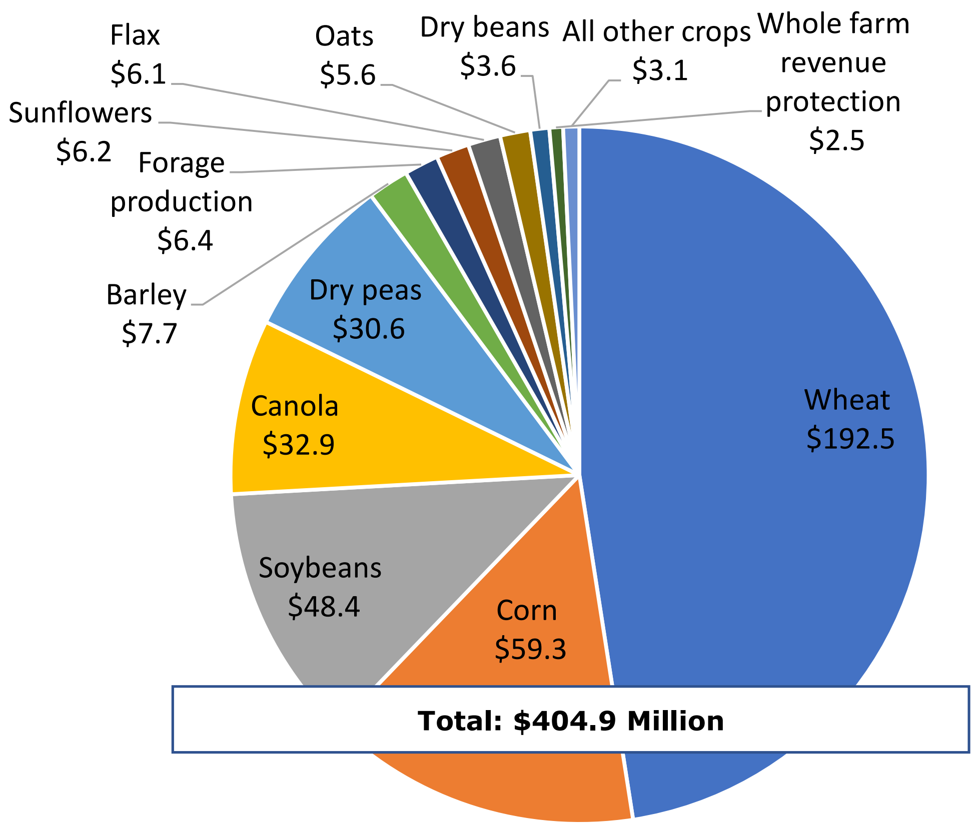
The 2017 drought prompted some of North Dakota's longtime farmers and ranchers to say the conditions were the worst they had ever seen (Nicholson 2017). Indeed, the week of July 25, 2017 was the most intense drought period in North Dakota since the US Drought Monitor started in 2000 (US Drought Monitor 2020). The disaster came on quickly in the spring and summer. By the end of the year, only one of the state's 53 counties had escaped severe drought status, the southeastern county of Richland (Jencso et al. 2019).

The drought was devastating for North Dakota agriculture, which is an $11-billion-per-year industry (Nicholson 2017). The state has more than 30,000 family farms and ranches, and 90 percent of its land is devoted to agriculture (NDDA 2017). Largely because of the prominence of agriculture in the state's economy, total costs of the drought were estimated to amount to 1-2% of state GSP (NOAA 2020a).

Livestock producers were especially hit. As of October 1, 2017, nearly 50% of the state's pastureland was in poor or very poor condition (Sankar 2017). Producers had to cull their herds, selling cattle at below market price. One producer brought his herd down to 100 head, the minimum he could have and still maintain basic genetics. The Federal Livestock Forage Program, which compensates eligible livestock owners in severe to extreme droughts, paid out $61.4 million to North Dakota livestock owners for forage losses. In addition to the challenge of keeping cattle fed, an added threat was water; in drought, as water holes become dry and water evaporates, salts and minerals become dangerously concentrated for cattle, potentially killing them (Leinen 2018).

Farmers fared no better in the historic drought, many of them chopping their stunted and withered cornstalks long before harvest time, to sell them to cattle owners as feed. Total crop losses for the state were an estimated $404.9 million. The wheat crop was hit particularly hard; by value, three times more wheat was lost than any other crop—or approximately $192.5 million in wheat, followed by $59.3 million in corn, $48.4 million in soybeans and $32.9 million in canola (see Figure 14).

Figure 14. Crop Losses in North Dakota Drought, $Millions, 2017



Sources: USDA 2017.

Although the drought seemed to strike hardest in the southeastern part of North Dakota, farmers in counties all over the state reported crop losses. The county with the highest reported losses was Hettinger County in the southwest, on the South Dakota border, at over $38 million (see Table 15). Next were nearby Stark County, with over $27 million in crop losses, and Grant County with over $22 million.

Table 15. Top Five ND Counties with Crop Losses Affected by Drought, 2017

County	USDA-reported Crop Indemnities*	Crop Type
Hettinger	$38,162,000	Wheat, canola, corn, sunflowers, flax, dry peas, barley, forage product, soybeans, oats, safflower, mustard, forage seeding, rye, other
Stark	$27,730,000	Wheat, corn, canola, sunflowers, dry peas, forage product, oats, barley, flax, soybeans, mustard, forage seed
Grant	$22,670,000	Wheat, corn, canola, sunflowers, dry peas, forage product, oats, barley, flax, soybeans, mustard, safflower, forage seed, other
Morton	$20,937,000	Wheat, corn, barley, oats, sunflowers, forage product, dry peas, canola, soybeans, flax, forage seed
Williams	$19,072,000	Wheat, dry peas, canola, barley, flax, corn, soybeans, sunflowers, oats, forage product, mustard
5-County TOTAL	**$128,571,000**	

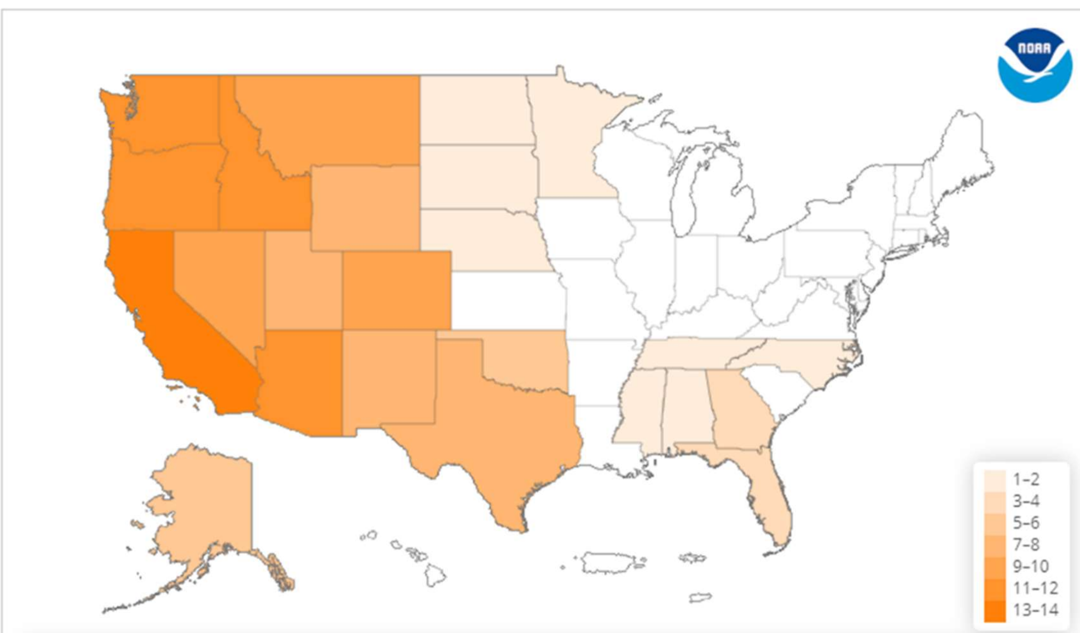
Source: USDA 2017. ***Indemnities are as reported (in 2017 dollars) and are rounded to the nearest thousand. Causes of crop indemnities include "Drought" and "Heat."

VIII. Wildfires

- Total CPI-adjusted direct cost of billion-dollar wildfires since 1980 was **$80.4 billion**. In 2017 and 2018, it was **$18.7 billion** and **$24.5 billion**, respectively.
- Annual length of US western wildfire season in the 1970s: **5 months.** Length in recent years: **8.5 months**
- Predicted increase in acres burned in western US by 2050: **2-6 times present levels**

Wildfire is an uncontrolled, unplanned fire that occurs in areas of combustible vegetation such as trees, grasses, or shrubs (NPS 2018). Wildfires can cause devastating losses in human life, crops, soil and forage for wildlife and livestock, and in damage to property, infrastructure, and public utilities. They can worsen local and regional air quality, increase respiratory illness, and reduce outdoor tourism. What makes specific geographies more vulnerable to catastrophic wildfires is a combination of heat, wind, dryness, and available fuel. Some or all of these conditions apply throughout the western United States, parts of the Southeast, and Alaska (see Figure 15).

Figure 15. Number of US Billion-Dollar Wildfires, 1980-2019



Source: NOAA 2020. Note: Billion-dollar designation is based on CPI-Adjusted costs (2019 dollars).

Climate change does not spark wildfires, but it makes it easier for them to start and spread. Dozens of observational studies link the global increase in wildfire conditions to the warming climate (M. W. Jones et al. 2020). Researchers have demonstrated that, since 1984, human-induced climate change is responsible for doubling the cumulative area of forest fires across the western United States (Abatzoglou and Williams 2016). Rising temperatures produce conditions ideal for wildfires: the number of hot days is climbing; forests and grasslands are dried out by increased evaporation; the growing season is lengthening (providing available fuel for longer periods); and snowpack is melting earlier (USGCRP 2017c). Since the 1970s, the annual average wildfire season in the Western United States has expanded from five months to 8.5 months long (Kenward, Sanford, and Bronzan 2016). It now burns six times as many acres and consists of three times as many large fires—those defined as more than 1,000 acres (Kenward, Sanford, and Bronzan 2016).

Along with the warming climate, past forest management policies have played a role in the increase in wildfire size. For several decades after the US Forest Service was established in 1905, the policy was to prevent fires and to quickly suppress any fire that started (Forest History Society n.d.). Forest managers in the 1960s began to realize that fire is part of the natural cycle of regrowth, with many plant species requiring severe fires to germinate, thrive, and reproduce (Hutto 2008). Therefore, suppressing all wildfire was disrupting valuable natural cycles of plant species and, in turn, of the animals that depend on them. In addition, the all-fire-suppression policies had the unintended effect of making more fuel available for massive future fires to spread unchecked across ever-greater acreages. Today, forest managers use "prescribed fire," also sometimes called "controlled burn." This helps improve diverse habitats and protect endangered species. Controlled burn also reduces fuels that, having built up over time in areas where natural wildfires have been long suppressed, could in the future lead to large, destructive fires (National Park Service 2020).

Between 1980 and 2018, California experienced 14 different billion-dollar wildfires, and Arizona, Idaho, Oregon and Washington all were affected by 11-12 such disasters. Western wildfires in 2017 cost $18.7 billion, destroying over 15,000 homes, businesses and other structures in California. The very next year, western wildfires cost an estimated $24.5 billion, burning over 8.7 million acres, well over the previous decade's average of 6.8 million acres burned per year (NOAA 2020a).

> Nationally, 2017 was the Forest Service's costliest year ever; at $2.4 billion, it exceeded the funding available, prompting officials to observe that wildfire is increasingly consuming the agency's budget. In 1995, firefighting accounted for 16% of the annual budget, and in 2017, 44%. Spending so much on firefighting means less budget is available for other aspects of forest management, including the very practices that reduce the risk of future fires (USFS n.d.).

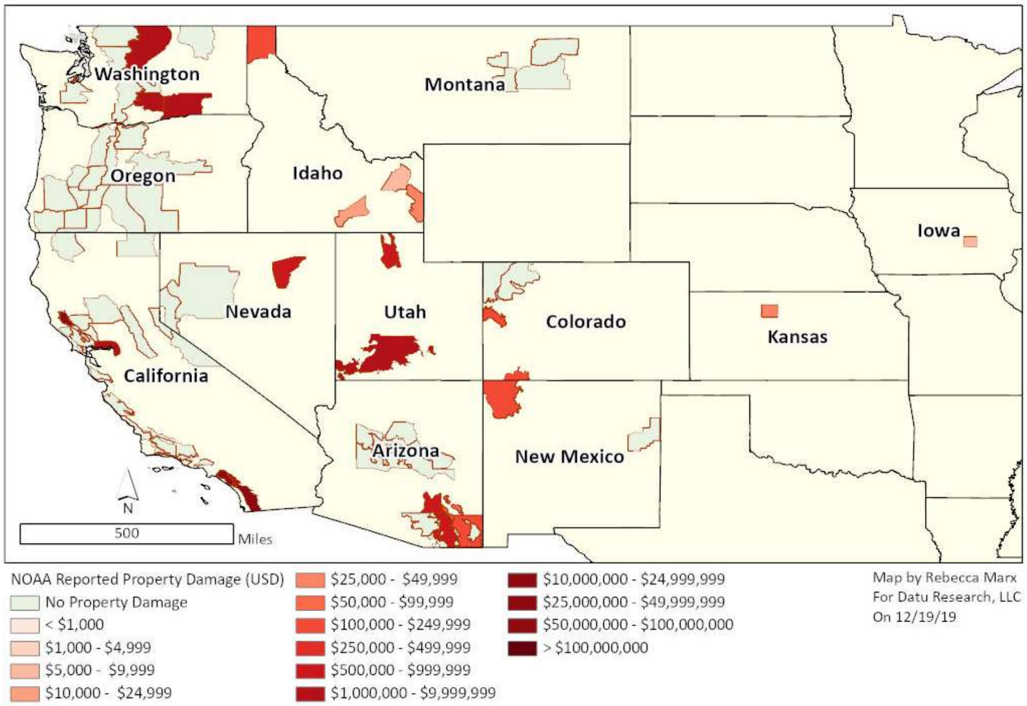
Costs are going up not only because wildfires are burning more extensive areas, but also because more assets are at risk. Development patterns are changing, increasing the number of people living in the "wildland-urban interface," where wildfires are most common. Researchers say this creates more opportunity for human-ignited fires, even while making it more difficult to suppress the fires when they happen. A calculation comparing the decades 1985-1994 versus 2005-2014 indicates that the area burned annually doubled while spending on federal wildfire suppression tripled (Radeloff et al. 2018).

Climate models project a continued increase in frequency and intensity of wildfires with rising temperatures (Kenward, Sanford, and Bronzan 2016). Higher wildfire risks are expected across the West and Southeast. Scientists suggest that in the western United States, by mid-century, the area burned each year could rise by a factor of 2-6 times from present levels (Reidmiller et al. 2018).

Western Wildfires, June–December 2017

Wildfires scorched the US West in 2017, most notably in Arizona, California, Colorado, Idaho, Iowa, Kansas, Montana, Nevada, Oregon and Washington. Over 9.8 million acres were burned, much higher than the 10-year annual average of 6.5 million acres. NOAA recorded a total of 66,131 fires in the season, with an average of 147.9 acres per fire—the second most since 2000. The fires destroyed homes, forced highway closures and evacuations, and devastated air quality across western states. At an estimated cost of $18.7 billion (NOAA 2020a), the wildfire season included some of the costliest single wildfires to date (Insurance Information Institute 2020a). It caused property damage across the region, as shown in Figure 16.

Figure 16. NOAA-reported Property Damage in Western Wildfires, Jun-Dec, 2017



Source: NOAA 2019.

The 2017 summer was hot and dry, with below-average rains. In many states, the wildfires were preceded, and exacerbated by, drought conditions. Low cloud coverage during the season added to hot temperatures. Most fires were sparked amid dry fuel conditions by lightning or human activity, and spread by strong, gusty winds and very low humidity (Di Liberto 2017).

California dominated the news in the 2017 wildfire season, yet other states also suffered from an extraordinary season, if not nearly as well covered in the media. California had the most fires—over 9,000—compared to the state with the second-largest number, Montana, with over 2,000. But in acres burned, Montana suffered worse than any other western state—with nearly 1.4 billion acres, compared to California's nearly 1.3 million acres. Close behind California was Nevada, whose acreage burned was only slightly less than California's (see Table 16).

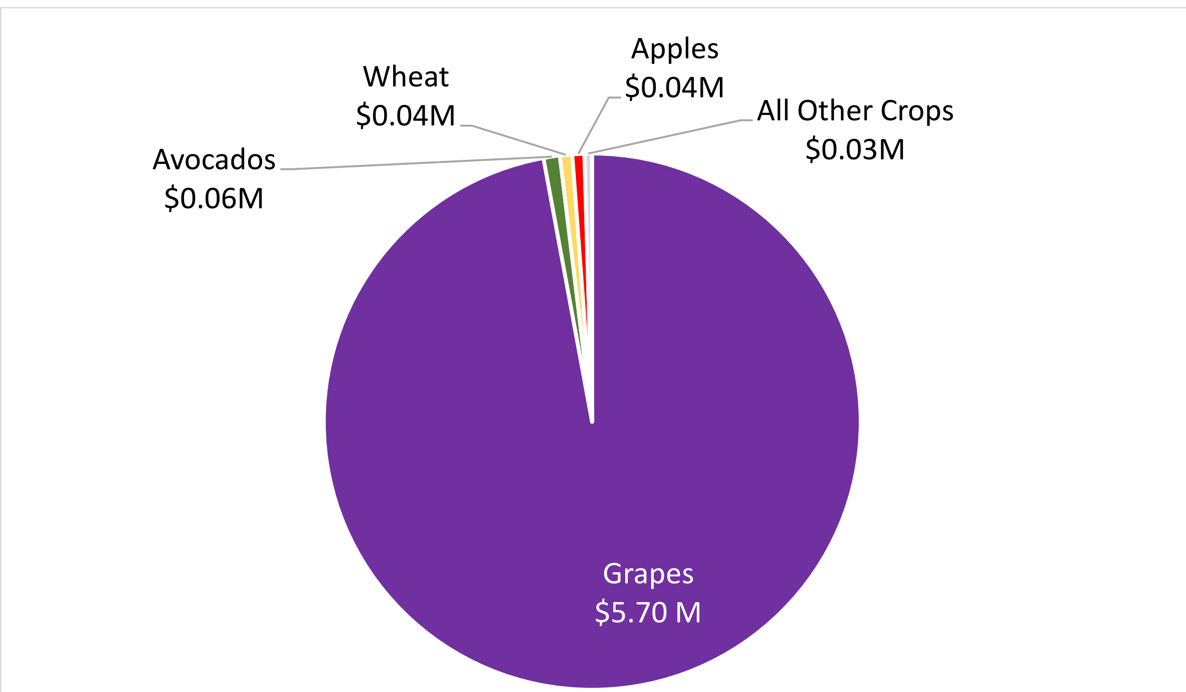
Table 16. Number of Fires and Reported Acres Burned in Western Wildfires, 2017

State	Number of Fires	NIFC-reported Acres Burned	State	Number of Fires	NIFC-reported Acres Burned
Arizona	2,321	430,000	**Nevada**	768	1,330,000
California	9,540	1,266,000	**New Mexico**	813	142,000
Colorado	967	112,000	**Oregon**	2,049	715,000
Idaho	1,598	686,000	**South Dakota**	1,420	77,000
Iowa	427	7,000	**Utah**	1,166	250,000
Kansas	71	476,000	**Washington**	1,346	404,000
Montana	2,422	1,367,000			

Sources: NIFC 2020.

The USDA recorded crop damage from wildfires in several states, but primarily in California. Grapes were by far the largest commodity lost (see Figure 17), largely because of California's fires, which account for about 93% of the grape losses. Grapes were also the source of highest crop loss in Washington state, where cherries and apples were also damaged or destroyed.

Figure 17. Aggregated Reported Crop Losses from Western Wildfires, Jun-Dec, 2017



Source: USDA 2017.

California Economy

Of the 2017 Western Wildfires, the California fires stood out for their record-breaking size, destruction, and deadliness. They arrived on the heels of five years of drought, followed by a wet winter, with unusually abundant rainfall that caused new brush growth. Later, record-breaking heat dried up that vegetation, turning it into fuel. At least 9,270 wildfires raged through the state, burning 1.5 million acres and causing 47 deaths. Some 10,280 structures were damaged or destroyed, a higher count than the previous nine years combined (Cal Fire n.d.-a).

California is vulnerable to wildfires at all times of the year, but those in the fall are especially dangerous. Warm winds come from the Great Basin—known as Santa Ana winds in Southern California and Diablo winds in the north—picking up speed as they blow through narrow canyons on their way to the coastal areas (Krishnakumar and Fox 2017). This dynamic helps explain the ferocity of the state's two worst firestorms in 2017: the Northern California Firestorm of at least 12 fires in the northern part of the state, beginning in early October; and the 29 Southern California Wildfires, which arrived in December and were not contained until January.

Among the economic costs of California's 2017 fires, perhaps the highest direct cost was in homes and businesses destroyed. Nearly one in three homes in California are in the wildland-urban interface, and about four million homes are in areas particularly vulnerable to wildfire (Cart and Lin 2019). Corresponding 2017 insurance payouts soared to then-highest on record, at nearly $12 billion for the October-to-December fires (Insurance Information Institute 2020b).

The colossal fires vastly surpassed the fire suppression budget of the California Department of Forestry and Fire Protection (Cal Fire), $426 million for the year; instead, total suppression costs, including state and federal resources, were tallied at nearly $1.8 billion (Associated Press 2018). Additionally, as the state was running out of resources, $1.3 billion from USACE was used to clean up debris in Northern California alone (NBC News 2018).

The wildfires affected California's farms, vineyards, and livestock. Agriculture is a large part of the local economy in many fire areas, relying mainly on fruit and nut crops, livestock, and poultry. In the Thomas fire in southern California, estimates for Ventura County alone put damage to current and future crops, equipment and buildings at nearly $171.3 million, hitting avocados and citrus crops hardest. The fire affected more than 10,289 acres of irrigated cropland and 60,000 acres of rangeland (Faber 2018).

Economic researchers have noted that, as devastating as the short-term expenses are—for instance, fire suppression, property loss, aid relief, and evacuations, among others—they pale compared to long-term damages. These include human casualties, degraded ecosystem services, extra water treatment, depreciated property values, tax and business losses, landscape rehabilitation, and other natural resource losses. A recent study estimated that suppression and other short-term expenses represent about 35 percent of the total economic costs of wildfire. In comparison, degraded ecosystem services and other long-term damages account for 65 percent (Headwaters Economics 2018). These proportions suggest that California's total 2017 wildfire cost will be in the tens of billions of dollars.

Despite all the ways in which the 2017 fires were unprecedented, they maintained their record-breaking status only until the following year. In 2018 came the deadliest and most destructive wildfire yet, the Camp Fire, in November 2018, killing 85 people and destroying 18,804 structures (Cal Fire 2019b). Many observers of California's experience have asked themselves if catastrophic wildfires have become the new normal. Indeed, the two-year period of 2017-2018 accounts for six of the top ten most destructive California wildfires on record (see Table 17).

Table 17. Top 10 Most Destructive California Wildfires on Record

	Fire Name	Date	County	Acres	Structures
1	**Camp Fire**	November 2018	Butte	153,336	18,804
2	**Tubbs**	October 2017	Napa & Sonoma	36,807	5,636
3	**Tunnel-Oakland Hills**	October 1991	Alameda	1,600	2,900
4	**Cedar**	October 2003	San Diego	273,246	2,820
5	**Valley**	September 2015	Lake, Napa & Sonoma	76,067	1,955
6	**Witch**	October 2007	San Diego	197,990	1,650
7	**Woolsey**	November 2018	Ventura	96,949	1,643
8	**Carr**	July 2018	Shasta & Trinity	229,651	1,614
9	**Nuns**	October 2017	Sonoma	54,382	1,355
10	**Thomas**	December 2017	Ventura & Santa Barbara	281,893	1,063

Source: Cal Fire 2019b.

Sonoma County

Of all the wildfires that ravaged California in 2017, the most destructive were likely the October fires in northern California, which struck worst in Sonoma County. According to Cal Fire statistics, the damage to the Sonoma-Lake-Napa area was over $6 billion (Cal Fire 2019a), although the damage figures grew much higher when insurance claims came in. The Tubbs Fire alone took 22 lives, damaged 317 residential and commercial structures, and destroyed 5,636 such structures (Cal Fire n.d.-b).

Known as the "Wine Country Fires," the Tubbs and other October fires generated at least $9.4 billion in claims for property, vehicle, and business losses; the vast majority, or 14,696 claims, were in Sonoma County (Kasler 2017). Sonoma suffered $430 million in real estate losses and $42 million in content losses, the highest among the counties most affected (see Table 18). Only Napa had greater losses in its grape crop, at nearly $3 million.

Table 18. Real Estate, Content, & Crop Loss in Northern CA Firestorm, October 2017

County	Real Estate Loss $	Content Loss $	Crop Loss $	Crop Type(s)
Sonoma	430,287,247	42,442,276	1,901,179	Grapes
Mendocino	23,557,202	30,633,550	406,101	Grapes
Napa	10,261,037	1,165,951	2,956,989	Grapes
Yuba	2,195,876	211,983	None reported	n/a
Lake	654,844	55,780	45,435	Grapes

Sources: SBA 2018; USDA 2017; NOAA 2020b.

About one-third of Sonoma County's economy is related to agriculture, wine, and tourism, including billions of dollars' worth of yearly income from winery tours. Most vineyards survived, 90 percent of the grapes having been harvested before the fires. Still, dozens of vineyards were severely damaged. Others had to close for lack of workers who had to evacuate their homes (Jhabvala 2017).

Over 70 percent of California's agricultural workers are Latinos. Many lost their jobs and homes, and growers voiced concerns that seasonal workers, facing the destruction of affordable housing options in the fires, could be forced to move elsewhere (Jhabvala 2017).

Air quality was severely affected in the fires. For nine days, an estimated seven million people in Northern California were exposed to air quality rated unhealthy and worse (O'Neill and Diao 2019). Smoke inhalation was especially a concern for farmworkers, many of whom were out in the fields during the fires, trying to harvest grapes worth hundreds of thousands of dollars. Particles from smoke increase the risk of respiratory diseases, asthma, and heart conditions (Barry-Jester 2019). Air quality is considered "very unhealthy" at an index level of 201; during the October fires, the air quality index in parts of Napa hit 486 (Yan 2017). Beyond respiratory effects, researchers recently studied the cardiovascular effects of wildfire smoke exposure, concluding that exposure to wildfire smoke increased out-of-hospital cardiac arrests. This risk appeared to be higher for people of lower socioeconomic status (Jones et al. 2020).

Santa Rosa, the county seat of Sonoma County, bore the brunt of the disaster in several ways. The 22 deaths from the Tubbs Fire were all in Santa Rosa, along with 3,000 homes lost, and $7 billion in property destroyed (Sager and Hall 2018). An estimated 7,000 Santa Rosa residents relocated after the fires, and Sonoma county faced potentially losing 1,300 residents (Quackenbush 2018). Santa Rosa City Schools, the county's largest school district, could lose $4 million in funds if attendance does not recover to pre-wildfire levels (Sager and Hall 2018).

Extreme Heat in Arizona

It is estimated that by 2050, days of high wildfire potential in Arizona will number 115 days per year, surpassed only by California (Climate Central n.d.). Escalating heat and drought are factors in Arizona's increase in wildfires, and the extreme heat itself is causing consequences in human health and labor productivity.

In June 2017, it was so hot in Phoenix, Arizona, the weather service used magenta—a color rarely seen on its maps—to indicate that the state would face "rare, dangerous, and very possibly deadly" heat (Wang 2017). The maximum temperature surpassed 95°F on June 13 and did not stop rising until it peaked at 119°F on June 20 (Weather Underground 2020). The seven-day stretch beginning Sunday, June 18 consisted of days that all were above 110 degrees. During the same period, the minimum daily temperature had risen from 81°F to 93°F, allowing for little nighttime reprieve from the heat (Weather Underground 2020).

In the air-conditioner installation business, workers can face 150°F heat in attics. Carlos Campoy, Installation Manager for George Brazil Air Conditioning & Heating in Phoenix, noted, "Sometimes, young workers wait too long to take a break and get sick…It happens at least once or twice every summer" (AZcentral 2018).

In the construction sector, workers have had to accommodate the heat with work-schedule changes. Laborers often work with asphalt that can get 15 to 20 degrees hotter than the outdoor temperature. This is why construction workers pour concrete at night, when the temperature might be below 90°F. "Everything out here is metal…I mean, it burns your hands," said a construction superintendent, Mike Wigness. Still, the nighttime workaround is limited by regulations if construction work is close to homes (Ventre 2016).

The US Occupational Safety and Health Administration (OSHA) indicated that employers should let workers rest several times a day to prevent exposure to heat for long stretches. Extra training for heat illness prevention is critical, and it may be necessary to provide workers with climate-controlled items such as cooling vests (Stephens 2017).

June 20 was not your typical day in Phoenix, where average June temperatures are usually between 105°F and 110°F (Wang 2017). As NWS meteorologist Chris Kuhlman reflected, "Normally, it's hot but it's not intolerable…But when it's even this far above what the normal is, even for us that live here…it's dangerous to be doing stuff outside. Anything, I suppose." (A. Wang 2017).

It was only the 16th day that had reached 118°F or higher since temperatures were first recorded in Phoenix more than 100 years earlier (11,060 days)—but it is striking that 15 of 16 of those occurred since 1989 (Freedman 2017). Although surpassing 118°F is not yet a typical week for Phoenix, it's not a stretch to imagine it could become one.

Among the expected impacts of extreme heat is loss of productivity. It can especially hinder the labor productivity of outdoor workers, such as those in construction, utility maintenance, landscaping, and agriculture. One estimate finds that extreme heat reduces productivity in high-risk sectors by three percent (Risky Business Project 2014). In addition to making workers more lethargic, laboring in hot weather or direct sun poses a risk of heat illness (Stephens 2017).

Extreme heat can prevent the body from maintaining a normal temperature. A skin temperature of 95°F is required for our core body temperature to be around 98.6°F, and it should never be more than 104°F. (Risky Business Project 2014). When the outside temperature is lower than our skin temperature, our body loses heat to the environment to cool down. If the outside temperature exceeds our skin temperature of about 95°F, we are entirely dependent on sweat to cool us down. In extreme heat, blood flow to the skin may stop, thus preventing sweating and cooling ourselves off, leading to heatstroke (BBC 2013).

Additional economic impacts include airline flight delays and cancellations, which happen when temperatures reach 118°F. Some planes simply cannot leave the ground. If the air is too hot, it is too thin for smaller jets such as those operated by American Eagle to generate enough lift for take-off (Wichter 2017). On June 21, 2017, at least 40 regional flights out of Phoenix's Sky Harbor International Airport were canceled (Wichter 2017), potentially affecting hundreds of other flights (Engel Bromwich 2017).

In periods of extreme heat, electricity use tends to soar, creating a self-reinforcing dynamic. For example, in the June 2017 Phoenix heat wave, power demand surged as electricity use reached record heights (Irfan 2019). Because older populations are susceptible to heat, and children's sweat glands are too underdeveloped to regulate temperature, having functioning air conditioners is a priority (Sinclair et al. 2007; Stephens 2017). But the measures we take to ensure our environments are livable during extreme heat may, in the long run, exacerbate the problem, according to David Sailor, a professor at Arizona State University and the director of its Urban Climate Research Center. "When you have these heatwaves, the residents in the area of course are using more air conditioning than they would otherwise," says Sailor. "So there's a lot more waste heat being dumped into the environment from their attempts to keep their buildings cool. That creates a kind of positive feedback loop between local heat and global climate change." (Engel Bromwich 2017).

As Phoenix's population continues to grow, so will the amount of concrete, and so will the heat. By 2030, the Phoenix population will grow from its current 1.6 million to an estimated 2.2

million, while the metro area will grow from 4.9 million to an estimated 6.3 million (IGG 2020; USCB 2020). Building to accommodate this population is a concern because it can increase the urban heat island effect, in which urban areas have higher temperatures than nearby countryside. The urban heat island effect is driven by human heat production and human-made materials such as asphalt and concrete (Mohajerani, Bakaric, and Jeffrey-Bailey 2017). The presence of pavement and the lack of natural cooling systems such as streams and forests can increase city temperatures by 5.4°F during the day and 22°F in the evening compared to surrounding areas (EPA 2020).

With continued urban growth and global warming, Phoenix and other regions are expected to experience more and more hot days in the future, and labor productivity is anticipated to decrease. Today Phoenix is among the one percent of metro areas that see more than 100 days of 95-degree heat. If emissions patterns do not change, by mid-century, a predicted 33 to 70 more days could be over 95°F in the Southeast (Risky Business Project 2014). Over a quarter of metro areas country-wide could see more than 100 days of 95-degree heat by mid-century (MBA EDGE 2019). For every extra degree-Celsius of warming (about 1.8°F), labor supplied by workers heavily exposed to outdoor temperatures is expected to decrease by .53 percent (Hsiang et al. 2017).

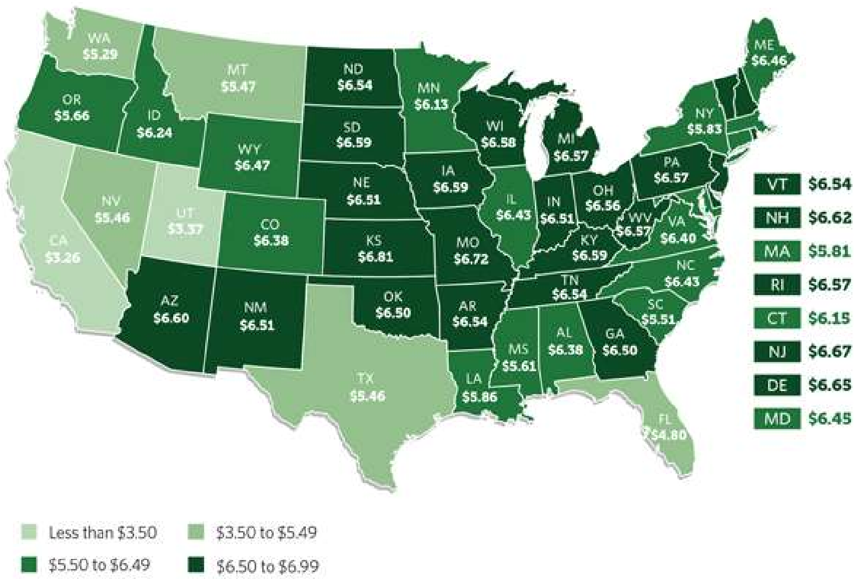
X. Reducing Emissions and Building Climate Resilience

The most critical response to worsening climate change-fueled weather disasters is to reduce emissions of CO_2, methane, and other greenhouse gases that are driving climate change. Without effective climate action, billion-dollar disasters will likely continue to become more intense and more frequent, overwhelming states' and municipalities' ability to recover—in some cases, before the next disaster hits.

The takeaway for many states and municipalities is that they need to 1) join the global effort to reduce greenhouse gas emissions, and 2) protect their communities by adapting to the impacts of climate change already underway. In some cases, this adaptation includes retreating from areas that are chronically vulnerable to worsening weather disasters.

Adaptation measures can be expensive, but the evidence shows that being unprepared costs even more. Adaptation projects to mitigate the impact of flooding—such as elevating buildings, constructing floodwalls, or rebuilding coastal wetlands—are a worthwhile investment in limiting damage from future disasters. In 2018, the National Institute of Building Sciences (NIBS) completed an interim study to compare the benefits and costs of federal natural disaster mitigation grants to states. The study found that the return on disaster mitigation is a nationwide ratio of $6 for every dollar invested (Multi-hazard Mitigation Council 2018). Following up on this research, the Pew Charitable Trusts performed a state-by-state analysis on NIBS' underlying data. Not surprisingly, the authors found that the disaster mitigation benefit-cost ratio varies by geography and event type—floods versus wildfires, for instance (see Figure 18). The analysis found that in California, each $1 invested in disaster mitigation saved $3.21 in disaster recovery; in Kansas, in contrast, each disaster mitigation dollar saved $6.81 (Stauffer, Foard, and Spence 2019).

Figure 18. Return on Investment, Federal Disaster Mitigation Programs 1993-2016



Source: Stauffer, Foard, and Spence 2019.

In congressional testimony in 2019, the GAO recommended that FEMA reduce the cost of future post-disaster responses by integrating hazard mitigation planning into the recovery process (GAO 2019). Meanwhile, out of necessity, states and local governments are leveraging federal and other sources to invest in climate resilience and hazard mitigation. Vulnerable localities and regions are increasingly crafting climate resilience plans for the future, with proactive measures to protect their communities against extreme weather disasters.

This report presents three case studies that embody planning, investing in the future, and collaborating with groups and individuals who have a stake:

- Cedar Rapids, a small Midwest city, endured a catastrophic flood a decade ago and vowed never to suffer the same fate again. Town leaders recognized that rebuilding in the most vulnerable risk area was simply not viable, so they worked to give residents the support they needed to relocate to safer ground.
- New York City, a vast metropolis, has a long-term plan to achieve 100 percent clean electricity and floodproof buildings in neighborhoods vulnerable to coastal flooding.
- The Rio Grande watershed in the arid Southwest has several regional stakeholders who are working to protect the environment their water comes from while giving residents the tools and resources to change their habits and save water.

Together, these case studies offer innovative examples and lessons learned for other cities and regions to draw on when designing their resilience planning. One case, New York City, stands out for combining its resilience efforts with a climate policy to make New York City carbon neutral by 2050. New York's example demonstrates that planning for the future in a warming world requires pushing ahead to adapt to climate change and reduce greenhouse emissions.

Cedar Rapids, Iowa

The year 2008 was anticipated to be the "Year of the River" by the City of Cedar Rapids, Iowa, as plans to spruce up the riverfront took the center of attention. Ironically, on June 13, 2008, Cedar Rapids experienced its most extreme flooding event on record. A combination of snowmelt and torrential rain caused the Cedar River to crest at over 31 feet, a record by almost 12 feet. The floodwaters covered 14 percent of the city, damaging 561 city blocks, affecting 7,198 parcels, and dislocating more than 18,000 residents (City of Cedar Rapids 2020). “The city filled like a bowl,” said Sandi Fowler, Deputy City Manager (Fowler 2020). Bridges tumbled, foundations cracked, City Hall was underwater, and the river kept rising as water flowed through homes and out of front doors (Maag 2008). The flood remains the largest on record in Cedar Rapids, causing $5.4 billion in damage (City of Cedar Rapids 2020b).

Just four days after the river crested, the City Council gathered to establish long-term recovery goals for Cedar Rapids. More than 2,600 residents participated in open houses to define neighborhood reinvestment and redevelopment plans. Work sessions, online discussion boards, formal stakeholder presentations, and one-on-one meetings allowed an array of stakeholders to voice their concerns. A flood management plan was approved just five months after the flood, and communities remained involved throughout the final design process (City of Cedar Rapids 2018).

Short term plan: buyouts

The substantial property damage attributed to the Cedar River flood made it clear that preventing future disasters would involve moving some structures entirely out of harm's way. The City responded by setting forth a buyout policy that included limited mandatory acquisitions and a greater voluntary buyout effort. The government purchased flood-prone or flood-damaged properties at or slightly above their pre-flood values, to convert the land into open space. Homeowners who volunteered for the buyout were eligible to receive down payment assistance for replacement homes, given an indefinite waiting period before buyouts would go through. The buyout allowed business owners and homeowners who did not stand a chance of making it through another flood to relocate "to safer pastures" (R. Smith 2014).

The buyout program removed over 1,300 properties from the flood zone. Most buyouts happened within the first three years after the flood. By the end of the program, 154 commercial properties and 1,183 residential properties had been purchased. "It started slow and then it really ramped up…It just enabled us to dramatically change our community," said Jedd Pomeranz, City Manager in 2010 (R. Smith 2014).

Long term: Infrastructure Construction

The Cedar River Flood Controls System (FCS) Master Plan provides direction for flood planning while giving flexibility for revisions. The 20-year plan includes detailed preparations for deploying removable barriers and other temporary measures and more ambitious, permanent "grey" infrastructure, such as levees, bridges, flood gates, and floodwalls. When complete, the system will span approximately 7.5 miles along the river (Munson 2016; City of Cedar Rapids 2018). The system design accommodates the same water volume as the flood of 2008 (City of Cedar Rapids 2018).

In addition to protecting against flooding, the FCS aims to increase the downtown riverfront's recreational and aesthetic appeal. "Aesthetic Guidelines" ensure cohesive designs that uphold physical standards and preserve neighborhood history. For example, proposed pump-houses seek to blend into the residential buildings of neighborhoods. Meanwhile, levees built for half the cost of floodwalls will feature planned green space on both sides. Rather than flood gates, removable floodwalls are planned for street closures to allow for more open views and increase connection with the river. A bicycle trail system along the levee corridor will connect the entire flood control project (City of Cedar Rapids 2018).

Progress to date includes two half-mile-long levees, one of which is topped with a concrete bicycle and pedestrian trail. Two bridges were raised over Prairie Creek. A completed pump station with a gate will prevent the river from backing up into neighborhoods through storm sewers. A 4.4-acre detention basin can store excess rain until it can be safely pumped back into the river (City of Cedar Rapids 2020a).

Fighting for funding

The City of Cedar Rapids has been pushing since 2008 to fund its $750-million Flood Control Plan. The Iowa Flood Mitigation Board committed $267 million over 20 years to the project, with the first disbursements in 2014 (Morelli 2019). This state program, the Growth Reinvestment Initiative (GRI), directs Cedar Rapids sales tax revenues to the flood system. In addition, the City of Cedar Rapids made a $110-million commitment and, as of early 2018, received $14 million in federal grants.

The missing financial piece for a full decade appeared to be funding from the USACE. The USACE signed off on a project design to protect the east side of the river in 2011, and Congress authorized its construction in 2014. It was not until July 2018, after Cedar Rapids sent a lobbyist to Washington DC, that the $117 million in funding was delivered to help pay for a permanent flood protection system (Morelli 2018; Morelli 2016).

Most funding for the buyouts came from the CDBG Program under HUD, but other sources also contributed. The Iowa Economic Development Authority approved $58.1 million for residential properties and $35.8 million for other properties. FEMA provided funds for the first 97 buyouts. Funds from the city's local-option sales tax contributed to 167 buyouts (City of Cedar Rapids 2018).

With approximately $100 million already spent on acquisition, engineering, and initial construction, flood control spending in Cedar Rapids is expected to more than double from $18.6 million in the 2019 fiscal year to $37.8 million in the 2020 fiscal year (Morelli 2019). More grants are still needed from the city, state, and private funders to fill the $342 million local funding gap (City of Cedar Rapids 2018). An additional shortfall of $50 to $65 million is projected as online sales displace sales tax revenue that has funded projects to date (Morelli 2019).

Lessons Learned

The swift and thorough response Cedar Rapids made to its extreme flooding event of 2008 can serve as a road map to other cities working toward inland flooding prevention and resilience more generally. Lessons learned include:

1. **Long-term planning is necessary:** Cities can benefit from creating long-term sustainability or resilience plans. Whole communities can be involved in resilience planning, ranging from residents and small business owners to industry stakeholders.

2. **Buyout programs can be effective and cost-saving:** Although ambitious buyout programs can be challenging, they can be an effective way of moving people and property out of harm's way. This approach to reducing assets at risk can be more affordable than making repeated repairs or retrofitting. It can be an essential step in reestablishing natural floodplains and environmental assets that reduce future flood risk. Buyout programs are best completed as swiftly as possible, with immediate assistance for residents and business owners seeking new properties and with a commitment to preserving community identity, culture, and history.

3. **Technical and aesthetic goals can be addressed simultaneously;** Cedar Rapids' intentional consideration of its residents' recreational, visual, and cultural desires has increased cohesion while making residents and businesses safe. The multi-faceted nature of the plans helps minimize flooding risk and maximize other social, economic, and environmental benefits.

4. **Funding** for resilience is available at the federal, state, and local levels. Collaboration is needed among planners and funders at each of these. Lobbying and relentless perseverance may be required to secure funding, even if it has already been authorized.

The plan to fill the remaining financing gap to fund Cedar Rapid's Flood Control Plan is still coming together, and it is clear that only perseverance has gotten the City this far. The effort put into retreating and fortifying now will, in the long run, save the Cedar Rapids both finances and heartache. As heavy precipitation events become more frequent, Cedar Rapids plans to become more resilient.

New York City

When Hurricane Sandy arrived in New York City in October 2012, residents were unprepared for the powerful storm surge and heavy winds. Waters flowed from the ocean, flooding neighborhoods and critical infrastructure. Hurricane Sandy destroyed approximately 300 homes and damaged 69,000 residential units. The cost of damage to New York City, including lost economic activity, was roughly $19 billion (NYC Recovery 2020).

Hurricane Sandy is a prime example of how sea-level rise has contributed to higher storm surges that move farther inland. Hurricane-driven flood heights have increased by 3.9 feet in New York City over the last thousand years (USGCRP 2018), and the pace of this rise is accelerating rapidly. The New York City Panel on Climate Change (NPCC) projects mid-range sea level rise to be 11-21 inches by the 2050s, compared to a 2000-2004 baseline; high-end estimates reach 30 inches (Gornitz et al. 2019). Today large sections of the coast in all five boroughs lie near or at water level, making them exceptionally vulnerable to future flooding.

Despite grim projections for a flooded future in New York City, city officials have not accepted this fate. "The projections we're hearing about today assume that we don't act…The good news here is that we as a city are continuing to act," noted Dan Zarrilli, director of the Mayor's Office of Recovery and Resiliency (Durkin 2015).

New York City is currently acting through its plans to address the sustainability of its buildings. Buildings are at the center of climate action and adaptation plans, both through ambitious building emissions reductions and planning for flood resilience.

A citywide plan to decarbonize buildings and invest in climate change solutions

Without global climate action, temperatures and sea levels in and around New York City will continue to rise; accordingly, the City has committed to being a global leader in reducing emissions, introducing aggressive legislation to reduce carbon emissions from buildings. In response to the estimate that buildings accounted for 67 percent of the city's greenhouse gas emissions (The City of New York 2017), the April 2019 law aims to reduce carbon emissions from large buildings by 40% over the next decade (DiChristopher 2019). It will contribute to an overarching goal of reducing city-wide emissions by 80% by 2050 compared to 2005 levels. The carbon limit will be enforced with an annual fine of $268 per metric ton of CO_2 over the limit, starting in 2024 (Malin 2020). The City has set a target of increasing city pension fund investments in climate change solutions to $4 billion by 2021 (City of New York 2019).

A resilience plan to floodproof businesses

In addition to relocating some buildings out of the most flood-prone areas, New York City has encouraged neighborhood resilience strategies. Plans have been developed to address neighborhood-specific development, zoning, and land-use change related to flooding in each of the boroughs (NYC Planning 2020).

For instance, in southern Queens, the neighborhoods of Rockaway Park and Rockaway Beach sit on the narrowest part of the Rockaway peninsula and are at risk of flooding from both the Atlantic Ocean and Jamaica Bay. Under new preliminary flood maps, nearly 95% of buildings sit below the base flood elevation at which, year over year, there is a 1% chance that a significant flooding event will occur. New York City building codes, as currently written, are not conducive to making the changes necessary to prepare for future flooding events (NYC Planning 2017).

Options for floodproofing are particularly limited in the commercial corridors of Rockaway Park and Rockaway Beach. Most buildings share a wall with an adjacent building, making them difficult to elevate, and alternatives to elevation, such as reinforceable flood-resistant walls, are prohibitively expensive. Relocating commercial activities to higher floors is an option, but this means forfeiting space, especially where building height restrictions prevent building above the current highest level. Some barriers to resilience investment have been removed temporarily, and a more permanent solution is in the works (NYC Planning 2017).

Fortunately, business owners have not been alone in their efforts. The Department of Small Business Services (SBS) is helping Rockaway businesses organize and prepare for flooding through the Business Preparedness Resiliency Program (Business PREP). Business PREP offers on-site resilience assessments, makes micro-grants for resilience improvements, and provides workshops to help businesses create continuity plans. The SBS gives businesses building retrofit options while trying to identify locations for below-grade activities.

Lessons Learned

New York City's plans to revamp its buildings to actively reduce the severity of climate change and prepare for its inevitable impacts can serve as an example to other cities. Broad lessons include:

1. **Current zoning and building codes require adjustment in a world with rising temperatures and sea levels.** Today's buildings lack adequate standards of efficiency and durability to be sustainable. Updated and proactive standards and zoning can make development more suitable for current and future risks.

2. **Neighborhood-level planning helps address communities' unique flood risks.** Both the natural and built environments of communities need evaluation during resilience planning. It is essential to consider how specific policies or standards may not be suitable for all neighborhoods or could potentially exacerbate social equity issues.

3. **Floodplains require reevaluation and adjustment.** As sea levels rise in US coastal areas, more and more properties will lie in floodplains. Updated flood maps can help residents and business owners understand their flood risks.

New York City's decision to aggressively reduce emissions from buildings demonstrates the level of commitment needed to slow trends such as sea-level rise. In addition, the Rockaway Beach/Rockaway Park case indicates that property owners in vulnerable neighborhoods may need extra attention and specific policies to meet flood resilience goals. Only through climate action and intentional resilience planning will future generations of New Yorkers thrive in the same spaces they enjoy today.

Rio Grande Watershed and Albuquerque, New Mexico

Forested watersheds provide drinking water that more than 180 million Americans depend on (Othman 2017). In the western United States, some 65 percent of the freshwater supply comes from forested watersheds (EPA 2019). Because of the crucial roles forested lands play in storing and filtering water supplies, wildfire is a severe threat to a watershed's ability to provide clean water for farms, communities, industry, wildlife, and outdoor recreation.

This case study tells how a mega-fire and its impacts on drinking water inspired a diverse group of forward-thinking people to rally around their watershed. The initiative builds on the idea that if a community benefits from the ecosystem services that a healthy watershed provides, it should pay to help keep that watershed healthy (Postel 2017).[5]

[5] The Rio Grande Water Fund and many other water initiatives are ably documented by Sandra Postel, in Replenish: The Virtuous Cycle of Water and Prosperity, Island Press (Washington, DC: 2017). This case study provides recent updates to Postel's 2017 contribution.

The Rio Grande Water Fund

In 2011, the drought-driven Las Conchas Fire started in the Santa Fe National Forest and went on to burn 156,000 acres of forested land in northern New Mexico. Next came the all-too-familiar finale of the drought-wildfire-flooding cycle: thunderstorms pummeled the area after the fire, causing massive ash and debris flows. The Rio Grande loaded up with so much sediment it turned black, the water so full of ash it was not worth treating. Cochiti Lake had to close to recreation after receiving tons of fire debris (TNC 2019).

Two years after the Las Conchas Fire, the New Mexico office of The Nature Conservancy (TNC) convened an array of representatives from urban water utilities, federal and state forestry agencies, businesses, and stakeholders. This meeting was the launch of the Rio Grande Water Fund (RGWF) (Postel 2017). A public-private partnership, the Fund set a goal to restore 600,000 acres of forested watershed over the coming 20 years, by thinning overgrown forests, restoring streams and wetlands, and managing fire. The effort also educates youth, provides policy research, and creates forestry and wood-product jobs (TNC 2019).

The RGWF seeks to generate funds to sustain its 20-year program by attracting private investors and leveraging public funding. Since its beginning in 2014, the Fund has raised $5 million in private funding and leveraged $48 million in public funds. Five counties in northern New Mexico have provided financial support. In 2019, the New Mexico state Legislature unanimously passed a bill, signed into law, setting aside $2 million annually for forest and watershed restoration (RGWF 2019). The restoration efforts are an apt example of "pay more now to save much more, later." According to the project team's calculations, at $700 per acre, or $21 million per year for 20 years, the investment will save money even if only a single wildfire burns in this vital part of the Rio Grande watershed (Postel 2017).

Despite the many challenges of coordinating different agencies and their planning and funding cycles, the RGWF has already made progress by several key measures. By 2016, the Fund had restored 22,000 acres of forested land, and by 2019, this total had reached 140,000 acres. Having started with 40 charter signatories, the Fund today has 85, with a 2020 goal to reach 100 (RGWF 2019).

Recent research shows that the Fund’s investments in reducing wildfire risk and protecting source water are boosting local economies in northern New Mexico and southern Colorado. In 2018 alone, the Fund spent $855,000 on contractors in the region. Accounting for direct and secondary impacts, this supported an estimated 22 jobs, over $1 million in labor income, $1.3 million in value added, and nearly $2 million in economic output in the 17 western states (Huber et al. 2019). As the effort ramps up, the economic impact grows. According to the Fund’s annual report, it generated $18 million in total economic impact in 2019 (RGWF 2019).

Albuquerque-Bernalillo County Water Utility Authority

One of the original signatories to the RGWF is Albuquerque's municipal water authority, the Albuquerque-Bernalillo County Water Utility Authority (ABCWUA). The Authority was eager to participate in the RGWF, having already worked aggressively since the mid-1990s to replenish its rapidly diminishing groundwater supplies. The ABCWUA continues to provide substantial support to the Fund and serve on the Fund's executive committee.

Albuquerque has spent over two decades aggressively trying to save its groundwater resources. In 1992, US Geological Survey scientists discovered that the city's aquifer, its only drinking water source, held much less water than believed previously. Later it was established that the groundwater was being pumped at twice the rate of replenishment, and it had become dangerously low (Postel 2017). Knowing it had to act effectively to avoid future water shortages, the ABCWUA created its Water Resources Management Strategy, released in 1995.

The plan emphasized conserving water resources, improving water efficiency, and reusing non-potable water for irrigation. A $500-million program for water recycling and reuse was completed. Leaks in the distribution system were repaired. Perhaps the single most crucial water-saving category was and continues to be outdoor water use. Albuquerque residents use 40 percent of their drinking water on their yards. Instead of imposing a mandatory day-of-the-week watering program (as many jurisdictions do), Albuquerque makes it voluntary and flexible. It allows residents to pick their watering days, according to a 1-2-3-2-1 "Water by the Numbers" guideline—once weekly in March, twice weekly in April and May, three times weekly in June, July, and August, twice weekly in September, and once weekly in November. The system also assesses fees for water waste violations. These are primarily for landscape irrigation—which is considered a waste if it occurs between 11 a.m. and 7 p.m. Other water waste categories include faulty equipment such as broken sprinklers or leaky air conditioners. The Authority pays residents to convert to drought-tolerant landscapes, called xeriscaping, from *xerós,* the Greek word for dry (ABCWUA n.d.).

Albuquerque's conservation measures have worked well. By 2019, customers had reduced their daily water use to 121 gallons per person, less than half the 250-gallon rate in the mid-1990s. "So we're now using the same amount of water, even though we have 80 percent more people," says Katherine Yuhas, Water Resources Division Manager for the Authority. The current aim is to reduce per-capita water use further, getting it down to 110 gallons per person per year in the next 20 years, a reduction that will extend the water supply by 30 years (ABCWUA 2020). “This pushes out how long we go,” says Yuhas, “before we need to augment supply.” (Yuhas 2020).

Even more critical for restoring the groundwater is the Albuquerque's San Juan-Chama Drinking Water Project. This ambitious 4-year construction project, completed in 2008, switched most of the drinking water supply to surface water. The effort required $450 million to build a water treatment plant and 38 miles of underground pipeline to divert and treat water from the neighboring Colorado River Basin—water that Albuquerque is entitled to as its share of the river's apportionment among the Western states. Today, surface water supplies 80 percent of the community's water supply. After 20 years of efforts to restore the aquifer, the groundwater levels are rising, and declines—called "drawdown"—are significantly reduced. The Authority is working further to relieve strain on the aquifer by injecting it with river water (Chamberlain 2019).

Albuquerque is now preparing for future resilience, recently updating its water management strategy for the next 100 years. The plan, Water 2120, recognizes that population growth is a critical factor in determining demand, even as a warming climate and drier future restrict supply. Among the anticipated climate-related impacts are inadequate snowpack in the mountain watersheds that provide surface water, and the potential need to stop diverting water to ensure sufficient river flow. By thinking far ahead, the Authority is creating a framework for finding alternative water supplies to avoid depleting its groundwater as in the past. Water 2120 also includes a Source Water Protection Program to protect groundwater and surface water sources now and into the future (ABCWUA 2016).

What advice would Albuquerque give other water authorities who are planning for a drier future with climate change? "Set up a robust process that people can be a part of—and don't underestimate them," Yuhas recommends. "Really talk about the science, then use more good science to solve the problems." Albuquerque took two years to develop its plan, tapping the expertise of climate modelers, engineers, economists, hydrogeologists, and others—including their customers. In a series of meetings with the public, residents made comments, asked probing questions, and came to understand the inevitable tradeoffs.

“Our customers were given three different ways we could conserve over the coming 20 years,” said Yuhas. “Unanimously, in every meeting, everyone wanted the most aggressive conservation goal.” (Yuhas 2020).

Conclusion

This report draws on a growing body of climate science research that connects climate change to worsening weather disasters; shifting climate conditions in response to greenhouse gas emissions have been linked to fiercer storms, heatwaves, droughts, and wildfires. The best available science suggests that many weather disasters will undoubtedly worsen if greenhouse gas emissions continue unabated.

The United States in recent decades has seen a four-fold increase in the number of climate change-fueled extreme weather disasters, with a five-fold increase in direct costs. And this accounting captures only some of the direct costs—not even calculating the difficult-to-quantify cost in health, natural assets, and human lives.

Beyond these are even harder-to-quantify indirect costs, which are almost sure to dwarf the direct ones. Researchers are only now beginning to anticipate the indirect impacts in the form of lower asset values, weakened future economic growth, and uncertainty-induced instability in financial markets.

In the age of COVID-19, when the response to the virus and economic recovery will likely cost trillions of dollars, it is more important than ever to reduce the costs of climate change-fueled weather disasters. The likely consequences of continued greenhouse gas emissions demonstrate that unless we control climate-warming emissions, communities and whole economies in the coming decades will pay a devastating price—whereas investing in climate policy will deliver a high and sustainable rate of return.

Steady commitment is needed at the highest levels, nationally and internationally, to reduce greenhouse gas emissions. At the same time, even aggressively reducing emissions will only mitigate, but not stop, climate change. This fact is why cities, states, and regions also need to work together to build resilience to future weather disasters. Adapting to climate change, in some cases retreating from chronically vulnerable areas instead of rebuilding, will help ensure that communities have a safe, healthy, and economically stable place to live.

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Appendix 1: Federal Funding for Disaster Recovery

Most federal funding for disasters is tied to title IV of the Robert T. Stafford Disaster Relief and Emergency Assistance Act (Stafford Act), under which the President can declare a Major Disaster, on a state-by-state basis. In any natural event, including hurricane, tornado, snowstorm, drought, fire, and flood, a state governor can request a Declaration. The President—if convinced that the impacts of the event are beyond the ability of state and local governments to adequately respond—can grant the Declaration.

Agencies typically providing federal funding for disaster recovery include 1) the Federal Emergency Management Agency, 2) the US Army Corps of Engineers under the Department of Defense, 3) the Small Business Administration, 4) the Community Development Block Grants program under the Department of Housing and Urban Development, and 5) the Farm Service Agency under the Department of Agriculture, and 6) additional USDA disaster assistance programs.

1) Federal Emergency Management Agency (FEMA) Disaster Relief Fund (DRF)

Through The Disaster Relief Fund, FEMA provides emergency and disaster recovery funding for declared disasters. FEMA has two primary programs for funding: The Public Assistance Grants Program and the Individual Assistance and Household Program.

- *The Public Assistance Grants Program* assists communities in carrying out a quick response to disasters or emergencies declared by the government. Assistance comes in the form of Emergency Work or Permanent Work. Emergency Work addresses immediate threats and is used for activities such as debris removal and other emergency protective measures. Permanent Work funding is used for restoration of roads and bridges, water control systems, buildings and equipment, utilities, parks, or other facilities.
- *The Individual Assistance and Household Program* covers losses to individuals that are not covered by insurance. It comes in the form of Housing Assistance (HA) or Other Needs Assistance (ONA) and includes funding for crisis counseling, disaster unemployment assistance, legal services, and disaster supplemental nutrition. Considerations for Individual Assistance declarations include the fiscal capacity and resource availability of the state, uninsured home and personal property losses, the profiles of disaster-impacted populations, impacts to community infrastructure, casualties, and unemployment related to disasters (FEMA 2020b).

2) US Army Corps of Engineers (USACE) Disaster Relief

USACE under the Department of Defense is the primary agency responsible for assisting the Department of Homeland Security/FEMA in carrying out public works and engineering functions under the National Response Framework—a guide for how the Nation should respond to emergencies and disasters. In addition to coordinating federal public works and engineering-support activities, USACE helps prepare for, respond to, or recover from domestic emergency incidents by providing technical assistance, engineering expertise, or construction management. USACE also supports FEMA with search and rescue missions (USACE 2020a).

USACE responds to natural disasters under its own Emergency Management authority, Public Law 84-99. The Corps undertakes activities related to disaster preparedness, emergency operation, advance measures, drought assistance, emergency water assistance due to a contaminated water source, the Rehabilitation Program, and the Restoration Program. Both the Rehabilitation Program and the Restoration Program are concerned with the inspection and rehabilitation of projects that have been harmed by floods and coastal storms. USACE carries out its emergency work using pre-awarded contracts that can be activated quickly (USACE 2011). In non-emergency scenarios, congressional authorization is generally needed for USACE studies and projects before they are eligible for appropriation. Authorizations are required for both feasibility studies and for construction. Similarly, appropriations must be made for both the study and construction. Authorizations and appropriations are typically reviewed biennially. USACE has been granted some authority to carry out limited activities without congressional authorization.

Projects of limited scope are authorized under the Continuing Authorities Program (CAP). This program draws on authorities stipulated in Flood Control Acts, River and Harbor Acts, and Water Resources Development Acts. The maximum federal cost for planning, designing, and implementing an individual project is $10 million. States can request planning assistance from the USACE and receive federal funding for up to 50 percent of study costs (USACE 2020b).

3) Small Business Administration Disaster Loans

The SBA provides disaster loans to businesses, homeowners, and renters whose losses from a declared disaster are not covered by insurance or funding from FEMA. Assistance is available to businesses and private nonprofit organizations of all sizes.

Businesses must apply for disaster loans, and damages must be verified by the SBA. Insurance or other recoveries are reviewed after losses have been verified.

Loans cover physical damage, including real estate and contents. Real estate losses refer to damage to property consisting of land or buildings, and other immovable business property. Content losses include items such as inventory, machine and equipment and leasehold improvements. Loans also cover economic injury from operating expenses.

SBA loans cannot be made is excess of $2,000,000 for the repair or replacement of real estate, inventories, machinery, equipment or any other physical losses.

4) Community Development Block Grants for Disaster Relief and Recovery (CDBG-DR)

The CDBG program is administered by the Department of Housing and Urban Development (HUD). It is the largest source of funding available for state and local government-led economic development and neighborhood revitalization activities. The CDBG-DR program allocates funds to communities and states to respond and recover from presidentially declared disasters.
CDBG funding is typically appropriated for community development plans that incorporate 25 categories of eligible activities. Examples of these activities include real property acquisitions, housing assistance, and public service activities. Activities should principally benefit low-and moderate-income persons, though income-targeting provisions (that 70% of funds principally benefit low-and moderate-income persons) have been waived in the past to address urgent threats from disasters. CDBG-DR funds are prohibited from being used for activities that are covered by FEMA or USACE funds and the share of federal money that can be used for state administrative expenses is limited to five percent (Boyd 2011).
CDBG funds are traditionally used for:

- *Short-Term Disaster Relief*: CDBG is used to fill gaps in FEMA and SBA funding for emergency relief activities. It cannot substitute funding for FEMA or SBA activities. In the past, communities have used CDBG funding to remove debris, provide extra security, and restore essential services such as electrical and water.
- *Disaster Mitigation Activities*: CDBG funding is used for activities that reduce the impact of disasters. This includes supporting physical measures such as levee construction or earthquake-proof buildings. Disaster mitigation funds are also used to fund real property buyouts in areas prone to recurring events. Funds are furthermore used to run training exercises or public awareness programs. They are not typically used to compensate for low wages or revenues of businesses and workers.
- *Long-Term Recovery Activities:* CDBG funding can be used for long-term recovery and reconstruction, including business loans and infrastructure improvements. Funding can be for assistance to businesses and residents impacted by disasters as well as for grants intended to attract new businesses to the area.

HUD takes other actions to support disaster recovery, such as waiving certain program requirements or suspending statutory or regulatory provisions. Sometimes transferring funds to other programs is permitted. In some instances, communities may need to reach a certain match required to trigger assistance receipt. State and local governments may sometimes use CDBG funds to meet matching fund requirements of other programs (Boyd 2011). States are required to develop recovery plans that must be approved by HUD. They are also required to submit quarterly reports to the House and Senate Appropriations Committees that detail uses of funds.

5) USDA Farm Service Agency (FSA) Emergency Farm Loans

The Emergency Loan Program under the FSA provides loans for production and physical losses. Emergency loans can be made when a natural disaster or emergency is declared by the President or when a natural disaster is designated by the Secretary of Agriculture. Farmers with losses in counties that are designated as a disaster or quarantine area are eligible for loans, but only if they have experienced a 30-percent reduction in a primary crop. A 30-percent reduction in crop prices received for poorer quality crops due to a disaster could also meet loan eligibility requirements. Farmers can apply for loans on the FSA website (FSA 2020b). The Disaster Set-Aside Program exists so that producers who are not able to make a scheduled payment on an FSA loan are able to move a whole year's payment to the end of the loan (FSA 2020a).

6) Additional USDA Disaster Assistance Programs

Aside from Emergency Farm Loans, there are a multitude of programs that provide disaster assistance. Programs include:

- Livestock Forage Program (LFP)
- Livestock Indemnity Program (LIP)
- Emergency Assistance for Livestock, Honeybees, and Farm-Raised Fish (ELAP)
- Tree Assistance Program (TAP)
- Emergency Conservation Program (ECP)
- Noninsured Disaster Assistance Program (NAP)

All of these Disaster Assistance Programs provide financial assistance to producers or communities for losses attributable to adverse weather events. Programs address production and physical losses, ranging from damaged crops and trees to damaged land. Some programs make provisions for damages caused by events other than extreme weather, such as disease. The 2014 Farm Bill extended the disaster assistance programs indefinitely (FSA 2020a).

Appendix 2: CDBG Disaster Recovery Grants by State, 2010–2019

The following table presents Community Development Block Grant (CDBG) funding allocated to states for disasters from 2010 through June of 2019. CDBG funds are used for state and local government-led economic development and neighborhood revitalization. Funds are prohibited from being used for activities that are covered by FEMA, USACE or SBA funds.

State	Grant Total	Grant Count
Alabama	$ 175,294,078	8
Alaska	$ -	0
Arizona	$ -	0
Arkansas	$ -	0
California	$ 282,733,459	3
Colorado	$ 320,346,000	1
Connecticut	$ 213,556,359	1
Delaware	$ -	0
Florida	$ 1,525,020,000	3
Georgia	$ 64,904,000	2
Hawaii	$ -	0
Idaho	$ -	0
Illinois	$ 188,617,000	4
Indiana	$ -	0
Iowa	$ 96,887,177	1
Kansas	$ -	0
Kentucky	$ 13,000,000	1
Louisiana	$ 3,262,991,818	7
Maine	$ -	0
Maryland	$ 28,640,000	1
Massachusetts	$ -	0
Michigan	$ -	0
Minnesota	$ -	0
Mississippi	$ -	0
Missouri	$ 220,697,768	5
Montana	$ -	0
Nebraska	$ -	0
Nevada	$ -	0
New Hampshire	$ -	0
New Jersey	$ 4,205,027,506	2
New Mexico	$ -	0
New York	$ 8,935,771,963	5
North Carolina	$ 404,596,000	2
North Dakota	$ 195,331,418	4
Ohio	$ -	0
Oklahoma	$ 145,900,000	2
Oregon	$ -	0
Pennsylvania	$ 96,678,140	6
Rhode Island	$ 32,911,001	4
South Carolina	$ 513,303,000	9
South Dakota	$ -	0
Tennessee	$ 200,216,995	6
Texas	$ 10,588,004,686	10
Utah	$ -	0
Vermont	$ 39,592,211	2
Virginia	$ 120,549,000	1
Washington	$ -	0
West Virginia	$ 256,369,000	2
Wisconsin	$ -	0
Wyoming	$ -	0
Total	$ 32,126,938,579	92

Source: HUD 2019. Note: As of the publish date of the CDBG grant history report (June 20, 2019), an amount of $2.43 billion had been earmarked for "Flood, Wildfires, and other Events of 2017–2019" but had not yet been allocated. In addition, an amount of $1.68 billion earmarked for "Hurricanes, Wildfires, Volcanic Eruption and other Events 2018" was unallocated.

Appendix 3: FEMA Declarations by State and Disaster Type, 2010–2019

The following table contains a count of the Major Disaster Declaration and Fire Management Assistance Declarations made by US Presidents for each state from 2010 through 2019. Declarations require requests from state Governors, and they are granted if the President believes the impacts of the event are beyond the ability of state and local governments to adequately respond. The table indicates where events have historically occurred, but because of the limits of the natural disaster declaration process, it does not account for all major weather events.

State	Total FEMA Declarations	Hurricane	Flooding	Severe Storm(s)	Severe Winter Weather	Freeze	Wildfire
Alabama	13	4	0	9	0	0	0
Alaska	25	2	4	7	0	0	12
Arizona	45	0	2	5	0	1	37
Arkansas	15	0	2	11	2	0	0
California	208	0	4	9	0	0	195
Colorado	45	0	2	0	0	0	43
Connecticut	9	2	0	6	1	0	0
Delaware	4	2	0	0	2	0	0
Florida	17	6	0	3	0	0	8
Georgia	21	3	0	4	2	0	12
Hawaii	7	1	1	2	0	0	3
Idaho	31	0	6	3	0	0	22
Illinois	6	0	2	3	1	0	0
Indiana	4	0	1	3	0	0	0
Iowa	23	0	7	16	0	0	0
Kansas	36	0	1	12	3	0	20
Kentucky	18	0	4	9	1	0	4
Louisiana	13	4	5	4	0	0	0
Maine	8	2	0	5	1	0	0
Maryland	11	2	3	3	3	0	0
Massachusetts	10	2	0	6	2	0	0
Michigan	4	0	3	1	0	0	0
Minnesota	14	0	7	7	0	0	0
Mississippi	16	2	2	12	0	0	0
Missouri	13	0	4	9	0	0	0
Montana	47	0	5	5	0	0	37
Nebraska	22	0	4	13	1	0	4
Nevada	39	0	1	2	0	0	36
New Hampshire	18	3	1	11	1	0	2
New Jersey	14	2	0	9	3	0	0
New Mexico	53	0	5	6	0	0	42
New York	15	2	4	7	2	0	0
North Carolina	17	4	2	4	1	0	6
North Dakota	12	0	7	5	0	0	0
Ohio	6	1	2	3	0	0	0
Oklahoma	110	0	1	19	2	0	88
Oregon	65	0	2	6	0	0	57
Pennsylvania	9	2	2	3	2	0	0
Rhode Island	5	2	0	3	0	0	0
South Carolina	8	4	1	0	1	0	2
South Dakota	27	0	5	14	0	0	8
Tennessee	22	0	1	10	2	0	9
Texas	144	2	6	4	0	0	132
Utah	35	0	4	1	0	0	30
Vermont	16	1	4	10	1	0	0
Virginia	15	5	0	3	3	0	4
Washington	111	0	3	6	0	0	102
West Virginia	18	1	6	9	2	0	0
Wisconsin	11	0	4	6	1	0	0
Wyoming	23	0	3	2	0	0	18
Total	**1,478**	**61**	**133**	**310**	**40**	**1**	**933**

Source: FEMA 2020. Note: Includes Major Disaster Declarations and Fire Management Assistance Declarations
The "Hurricane" category includes Hurricane and Coastal Flooding; the "Severe Storm(s)" category includes Severe Storm(s) and Tornados; The "Severe Winter Weather" category includes Severe Ice Storms and Snow.

Appendix 4: USDA-Reported Crop Indemnities by State and Disaster Type, 2010-2019

The following table contains the aggregated value of crop indemnities caused by weather events reported to the USDA from 2010 through 2019. The “Indemnity amount” is defined by USDA as “the total amount of loss for a designated peril.” Although these figures indicate where crop damage attributed to weather events has occurred in the past decade, they do not reflect full losses.

State	Total Indemnified Crop Loss from Extreme Weather	Hurricane	Flooding	Severe Storm(s)	Severe Winter Weather	Freeze	Wildfire	Drought
Alabama	$ 274,229,310	$ 29,804,216	$ 88,171,711	$ 3,896,940	$ 1,397,947	$ 4,458,860	$ 18,837	$ 236,050,457
Alaska	$ 124,515	$ -	$ 73,083	$ 35,788	$ 34,763	$ 3,938	$ -	$ 84,789
Arizona	$ 38,913,889	$ -	$ 6,547,036	$ 18,082,849	$ 850,867	$ 11,011,926	$ -	$ 9,819,114
Arkansas	$ 229,187,741	$ 1,044,359	$ 991,629,518	$ 36,177,455	$ 22,011,045	$ 3,312,633	$ 110,686	$ 188,542,608
California	$ 1,126,995,446	$ 12,553	$ 727,622,848	$ 152,955,005	$ 134,437,015	$ 307,187,181	$ 14,680,867	$ 652,159,839
Colorado	$ 803,259,835	$ 3,809	$ 66,759,495	$ 386,557,151	$ 15,313,012	$ 35,303,319	$ 96,861	$ 381,298,696
Connecticut	$ 12,034,051	$ 974,527	$ 4,957,417	$ 5,441,190	$ 344,614	$ 2,321,319	$ -	$ 3,297,015
Delaware	$ 37,393,985	$ 252,890	$ 10,002,014	$ 320,687	$ 1,049,240	$ 30,069	$ 919	$ 36,789,419
Florida	$ 486,291,029	$ 242,443,079	$ 190,412,614	$ 53,321,648	$ 2,659,938	$ 111,347,452	$ 91,393	$ 79,087,457
Georgia	$ 1,110,186,880	$ 280,003,984	$ 199,636,331	$ 30,115,202	$ 9,760,240	$ 80,356,970	$ 40,844	$ 719,669,880
Hawaii	$ 8,645,753	$ 1,450,556	$ 896,544	$ 545,775	$ -	$ -	$ 42,683	$ 6,606,738
Idaho	$ 152,635,991	$ 25,475	$ 97,649,797	$ 39,376,058	$ 48,595,166	$ 37,186,826	$ 187,779	$ 75,859,853
Illinois	$ 3,377,411,478	$ 150,758	$ 1,684,293,655	$ 37,070,629	$ 42,953,788	$ 8,014,781	$ 526,027	$ 3,331,649,283
Indiana	$ 1,392,905,756	$ 96,803	$ 1,126,503,744	$ 34,197,927	$ 22,695,122	$ 6,397,233	$ 78,905	$ 1,352,134,888
Iowa	$ 2,534,581,584	$ 249,278	$ 1,501,513,838	$ 288,658,795	$ 42,926,404	$ 6,580,300	$ 75,720	$ 2,239,017,492
Kansas	$ 3,772,881,322	$ 272,972	$ 420,637,772	$ 459,881,843	$ 89,806,931	$ 59,126,731	$ 513,369	$ 3,253,086,407
Kentucky	$ 748,309,291	$ 776,484	$ 557,086,511	$ 34,969,291	$ 7,960,742	$ 15,469,310	$ 1,604,991	$ 695,489,215
Louisiana	$ 145,312,923	$ 4,673,251	$ 392,538,914	$ 17,020,346	$ 2,969,556	$ 4,402,449	$ 4,845	$ 119,212,033
Maine	$ 14,108,621	$ 11,540	$ 24,506,358	$ 2,426,359	$ 1,802,912	$ 3,754,673	$ 3,417	$ 7,912,632
Maryland	$ 107,934,509	$ 1,401,773	$ 32,267,447	$ 2,265,253	$ 2,354,755	$ 1,319,672	$ 70,818	$ 102,876,993
Massachusetts	$ 11,853,270	$ 687,066	$ 3,854,029	$ 2,766,190	$ 1,531,095	$ 2,724,890	$ -	$ 5,675,125
Michigan	$ 450,052,102	$ 15,332	$ 425,595,388	$ 25,077,467	$ 59,224,357	$ 140,007,988	$ -	$ 284,951,314
Minnesota	$ 810,626,835	$ 339,837	$ 2,108,320,551	$ 327,882,986	$ 142,518,438	$ 107,158,161	$ 96,950	$ 375,148,902
Mississippi	$ 254,884,660	$ 565,082	$ 600,136,491	$ 12,312,597	$ 5,904,620	$ 2,085,860	$ 3,422	$ 239,917,699
Missouri	$ 1,619,635,580	$ 37,733	$ 1,532,460,255	$ 39,768,331	$ 33,750,737	$ 2,769,464	$ 67,324	$ 1,576,992,728
Montana	$ 757,052,034	$ 150,081	$ 177,686,353	$ 293,232,512	$ 38,171,946	$ 24,192,800	$ 130,409	$ 439,346,232
Nebraska	$ 2,665,881,882	$ 98,324	$ 401,074,790	$ 1,043,595,974	$ 57,141,161	$ 25,892,901	$ 908,500	$ 1,595,386,184
Nevada	$ 6,981,012	$ -	$ 768,074	$ 1,022,113	$ 927,951	$ 3,176,484	$ -	$ 2,782,416
New Hampshire	$ 2,498,057	$ 1,158	$ 259,877	$ 820,738	$ 673,839	$ 1,180,160	$ -	$ 496,001
New Jersey	$ 21,565,987	$ 351,364	$ 8,796,776	$ 1,191,714	$ 959,292	$ 1,747,103	$ -	$ 18,275,806
New Mexico	$ 182,339,350	$ 100,924	$ 1,766,142	$ 44,507,354	$ 4,494,386	$ 13,886,839	$ 127,680	$ 123,716,554
New York	$ 220,563,282	$ 2,184,245	$ 203,858,078	$ 56,205,884	$ 20,300,923	$ 100,577,998	$ 755	$ 61,594,399
North Carolina	$ 1,277,038,923	$ 361,579,751	$ 556,890,748	$ 76,890,260	$ 15,524,818	$ 102,782,733	$ 173,569	$ 735,612,610
North Dakota	$ 1,593,057,136	$ 383,933	$ 3,042,760,971	$ 679,170,689	$ 165,222,128	$ 77,392,221	$ 119,807	$ 835,990,486
Ohio	$ 480,936,348	$ 331,027	$ 940,435,490	$ 10,391,021	$ 20,695,907	$ 6,690,800	$ 45,185	$ 463,478,315
Oklahoma	$ 1,264,007,487	$ 47,200	$ 145,179,016	$ 129,211,772	$ 13,604,412	$ 69,320,815	$ 233,554	$ 1,065,194,147
Oregon	$ 125,138,792	$ -	$ 18,944,568	$ 10,273,413	$ 21,784,008	$ 24,126,612	$ 1,506,159	$ 89,232,608
Pennsylvania	$ 191,349,500	$ 885,058	$ 108,176,430	$ 33,825,842	$ 5,583,935	$ 32,162,577	$ 3,685	$ 124,472,338
Rhode Island	$ 627,330	$ 98,701	$ 122,232	$ 98,784	$ 34,113	$ 129,799	$ -	$ 300,047
South Carolina	$ 372,785,830	$ 44,111,199	$ 181,174,933	$ 10,543,328	$ 2,343,162	$ 82,156,616	$ 501,813	$ 235,472,875
South Dakota	$ 1,886,631,563	$ 103,596	$ 2,024,362,422	$ 319,553,677	$ 126,023,378	$ 30,456,599	$ 223,127	$ 1,536,294,564
Tennessee	$ 278,316,012	$ 651,582	$ 254,001,124	$ 7,891,313	$ 3,587,831	$ 7,303,518	$ 612,826	$ 261,856,775
Texas	$ 7,156,650,964	$ 39,311,456	$ 1,176,295,058	$ 1,327,565,117	$ 60,133,819	$ 190,299,996	$ 345,542	$ 5,599,128,853
Utah	$ 16,415,152	$ 12,103	$ 1,562,261	$ 646,689	$ 3,935,929	$ 7,221,705	$ 11,959	$ 8,522,696
Vermont	$ 9,845,411	$ 121,418	$ 12,839,049	$ 4,121,036	$ 1,612,499	$ 1,539,830	$ -	$ 4,063,128
Virginia	$ 316,917,752	$ 9,393,965	$ 76,699,052	$ 20,576,547	$ 7,268,297	$ 28,432,929	$ 15,756	$ 258,498,555
Washington	$ 604,468,522	$ 8,369	$ 70,133,857	$ 102,883,741	$ 90,691,044	$ 136,390,215	$ 1,165,396	$ 364,020,801
West Virginia	$ 9,087,343	$ -	$ 2,347,994	$ 1,402,598	$ 120,460	$ 1,561,197	$ 708	$ 6,122,840
Wisconsin	$ 529,427,515	$ 170,735	$ 546,250,823	$ 36,027,874	$ 85,333,560	$ 32,077,303	$ 8,876	$ 461,142,727
Wyoming	$ 64,362,884	$ -	$ 7,470,026	$ 33,719,387	$ 7,005,758	$ 12,730,415	$ 8,874	$ 17,904,208
Total	**$ 39,554,342,423**	**$ 1,025,389,542**	**$ 22,753,929,504**	**$ 6,256,493,140**	**$ 1,446,027,864**	**$ 1,965,762,168**	**$ 24,460,837**	**$ 30,282,236,736**

Source: USDA 2008-2018. Cause of Loss Historical Data Files.

Notes: The "Hurricane " category includes Hurricane, Tropical Depression, Storm Surge, and Cyclone; the "Flooding" category includes Flood, Excess Moisture/Precipitation/Rain; the "Severe Storms/Tornado" category includes Wind/Excess Wind, Hail, Tornado and Other (Snow, Lighting etc.); the "Severe Winter Weather / Freeze" category includes Cold Wet Weather, Cold Winter; the "Freeze" category includes Freeze and Frost. The "Wildfires" category only accounts for losses attributed to fire; the "Drought" category includes Drought, Heat, and Hot Wind.

Appendix 5: SBA Verified Losses to Businesses by State and Disaster Type, 2010–2019

The following table contains total losses to businesses from weather events reported to and verified by the SBA from 2010 through 2019. Because the SBA only provides loans for uninsured damages, this data likely does not reflect damages to insured businesses and is only indicative of where losses to businesses occurred.

State	Total	Hurricane	Flooding	Severe Storm(s)	Wildfire
Alabama	$ 146,980,515	$ -	$ -	$ 146,980,515	$ -
Alaska	$ 1,232,173	$ -	$ 1,232,173	$ -	$ -
Arizona	$ -	$ -	$ -	$ -	$ -
Arkansas	$ 31,040,675	$ -	$ -	$ 31,040,675	$ -
California	$ 781,567,547	$ -	$ 860,887	$ 44,770	$ 780,661,890
Colorado	$ 55,357,123	$ -	$ 55,357,123	$ -	$ -
Connecticut	$ 37,480,068	$ 35,563,147	$ -	$ 1,916,921	$ -
Delaware	$ -	$ -	$ -	$ -	$ -
Florida	$ 2,391,146,345	$ 2,366,118,490	$ -	$ 25,027,855	$ -
Georgia	$ 131,837,786	$ 31,069,062	$ -	$ 100,768,724	$ -
Hawaii	$ 6,098,860	$ -	$ 6,098,860	$ -	$ -
Idaho	$ 206,496	$ -	$ 206,496	$ -	$ -
Illinois	$ 53,344,210	$ -	$ 16,830,021	$ 36,514,189	$ -
Indiana	$ 2,791,451	$ -	$ 1,222,110	$ 1,569,341	$ -
Iowa	$ 10,928,441	$ -	$ 2,281,153	$ 8,647,288	$ -
Kansas	$ 277,342	$ -	$ -	$ 277,342	$ -
Kentucky	$ 25,910,091	$ -	$ 1,313,445	$ 24,596,646	$ -
Louisiana	$ 2,300,111,576	$ 83,151,446	$ 2,210,174,073	$ 6,786,057	$ -
Maine	$ -	$ -	$ -	$ -	$ -
Maryland	$ 4,125,717	$ 4,125,717	$ -	$ -	$ -
Massachusetts	$ 36,511,695	$ 2,060,744	$ -	$ 34,450,951	$ -
Michigan	$ 30,611,722	$ -	$ 29,359,175	$ 1,252,547	$ -
Minnesota	$ 594,301	$ -	$ 594,301	$ -	$ -
Mississippi	$ 99,705,714	$ 5,206,853	$ 15,354,399	$ 79,144,462	$ -
Missouri	$ 197,506,083	$ -	$ 119,564,444	$ 77,941,639	$ -
Montana	$ 4,742,716	$ -	$ -	$ 4,742,716	$ -
Nebraska	$ 3,373,196	$ -	$ 3,373,196	$ -	$ -
Nevada	$ -	$ -	$ -	$ -	$ -
New Hampshire	$ 2,939,857	$ 2,939,857	$ -	$ -	$ -
New Jersey	$ 721,891,824	$ 715,666,828	$ -	$ 6,224,996	$ -
New Mexico	$ -	$ -	$ -	$ -	$ -
New York	$ 989,440,898	$ 951,523,584	$ -	$ 37,917,314	$ -
North Carolina	$ 882,596,658	$ 863,694,690	$ -	$ 18,901,968	$ -
North Dakota	$ 64,475,450	$ -	$ 64,475,450	$ -	$ -
Ohio	$ 56,080	$ -	$ 56,080	$ -	$ -
Oklahoma	$ 39,447,593	$ -	$ -	$ 38,186,216	$ 1,261,377
Oregon	$ -	$ -	$ -	$ -	$ -
Pennsylvania	$ 63,347,654	$ 4,357,031	$ 58,990,623	$ -	$ -
Rhode Island	$ 36,533,525	$ 3,594,871	$ -	$ 32,938,654	$ -
South Carolina	$ 436,918,372	$ 286,983,831	$ 149,934,541	$ -	$ -
South Dakota	$ 2,600,928	$ -	$ 2,395,326	$ 205,602	$ -
Tennessee	$ 305,096,626	$ -	$ -	$ 159,292,100	$ 145,804,526
Texas	$ 5,865,495,148	$ 5,727,040,857	$ 90,762,581	$ 42,039,118	$ 5,652,592
Utah	$ -	$ -	$ -	$ -	$ -
Vermont	$ 44,221,002	$ 36,007,395	$ -	$ 8,213,607	$ -
Virginia	$ 6,900,851	$ 6,900,851	$ -	$ -	$ -
Washington	$ 389,844	$ -	$ 389,844	$ -	$ -
West Virginia	$ 39,460,456	$ -	$ 32,727,234	$ 6,733,222	$ -
Wisconsin	$ 7,709,569	$ -	$ 175,277	$ 7,534,292	$ -
Wyoming	$ 992,441	$ -	$ 992,441	$ -	$ -
Total	**$ 15,863,996,619**	**$ 11,126,005,254**	**$ 2,864,721,253**	**$ 939,889,727**	**$ 933,380,385**

Source: SBA FY2008-FY2018. "Businesses" Tab. Note: No business losses were attributed to winter storms or freezes. The "Severe Storm(s)" category contains Severe Storm(s) and Tornadoes.