In the Path of the Storm

Global Warming, Extreme Weather, and the Impacts of Weather-Related Disasters in the United States

Environment Minnesota Research & Policy Center

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ENVIRONMENT MINNESOTA
RESEARCH & POLICY CENTER

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Executive Summary

Weather disasters kill or injure hundreds of Americans each year and cause billions of dollars in economic damage. The risks posed by some types of weather-related disasters will likely increase in a warming world. Scientists have already detected increases in extreme precipitation events and heat waves in the United States, and the Intergovernmental Panel on Climate Change recently concluded that global warming will likely lead to further changes in weather extremes.

Since 2006[1], federally declared weather-related disasters in the United States have affected counties housing 242 million people – or roughly four out of five Americans. The breadth and severity of weather-related disasters in the United States – coupled with the emerging science on the links between global warming and extreme weather – suggest that the United States should take strong action to reduce emissions of global warming pollution and take steps to protect communities from global warming-fueled extreme weather events.

Weather-related disasters are common in the United States, affecting people in every part of the country. However, the number of people affected by weather-related disasters in 2011 was unusually high, and the number of extremely costly disasters was unprecedented.

- Since 2006, weather-related disasters have been declared in every U.S. state other than South Carolina. During this period, weather-related disasters affected *every county* in 18 states and the District of Columbia. (Alabama, Arkansas, Connecticut, Delaware, Hawaii, Iowa, Louisiana, Maryland, Maine, Massachusetts, Missouri, North Dakota, Nebraska, New Hampshire, New Jersey, Oklahoma, Rhode Island and Vermont.) (See Figure ES-1.)

- More than 15 million Americans live in counties that have averaged one or more weather-related disasters *per year* since the beginning of 2006. Ten U.S. counties – six in Oklahoma, two in Nebraska, and one each in Missouri and South Dakota – have each experienced 10 or more declared weather-related disasters since 2006.
- More Americans were affected by weather-related disasters during 2011 than in any year since 2004. The number of disasters inflicting more than $1 billion in damage (at least 14) set an all-time record, with total damages from those disasters of at least $55 billion.

Record-breaking extreme weather events were responsible for many of 2011's worst weather-related disasters.

- **Texas experienced the hottest summer (June through August) ever recorded in any U.S. state,** smashing the previous record set by Oklahoma during the Dust Bowl summer of 1934 by an astonishing 1.6 degrees. The high temperatures, combined with Texas' driest 12-month period on record, triggered an exceptional drought that ruined crops and led to the state's

Figure ES-1. Number of Declared Weather-Related Disasters Since 2006 by County

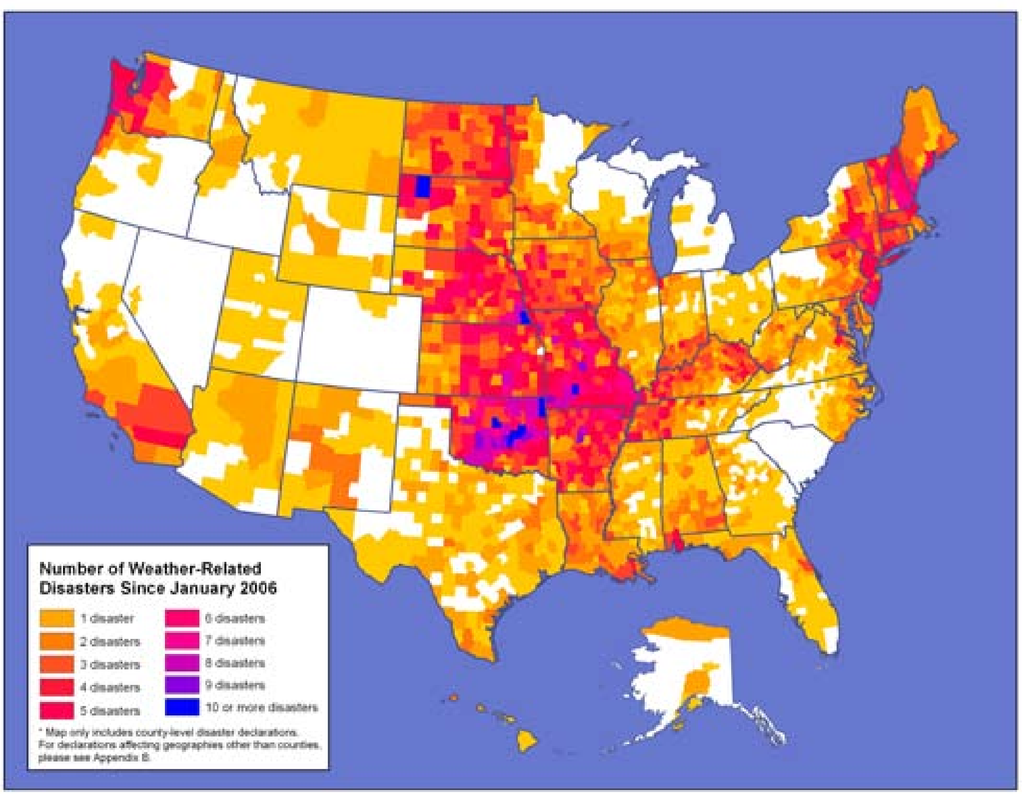
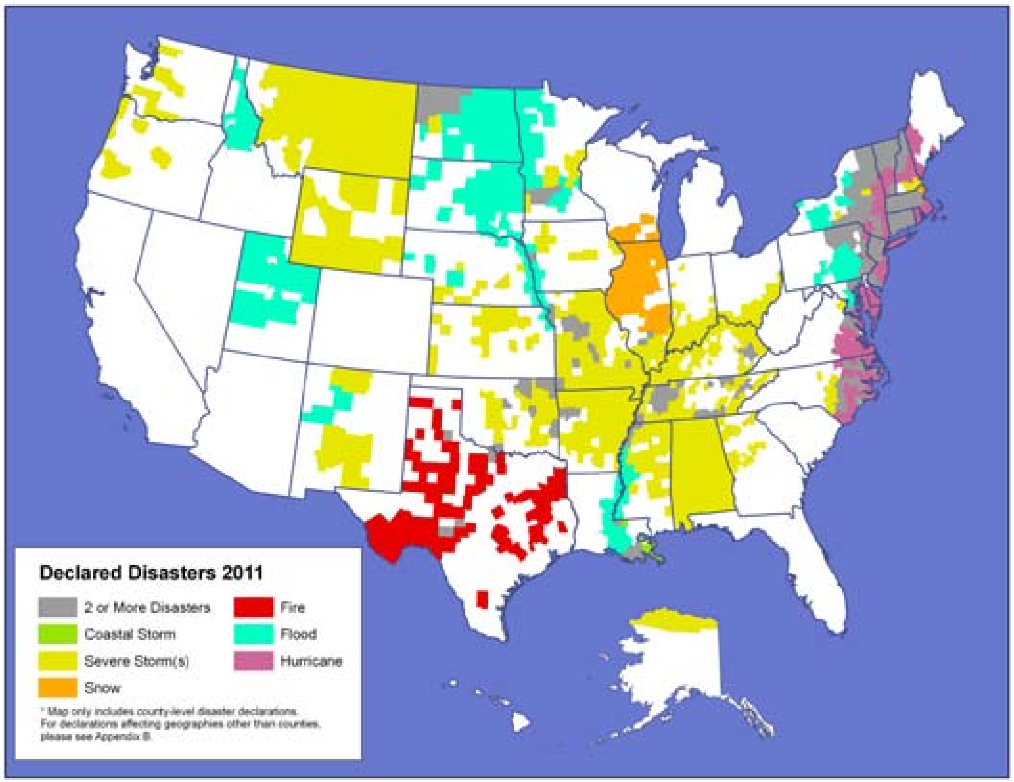


Figure ES-2. Declared Weather-Related Disasters in 2011 by Type of Incident



worst wildfire season in history. Wildfires claimed the lives of 10 people in Texas, while more than 20 people in Texas and Oklahoma perished from extreme heat.

- **Parts of the upper Plains experienced their wettest spring on record, contributing to massive flooding along the Missouri River.** The Missouri basin topped its all-time record for monthly runoff, while the nearby Souris River overwhelmed defenses that had been designed to withstand a 100-year flood, inundating much of Minot, North Dakota, and forcing cancellation of the North Dakota State Fair. At least five people died in flooding in the upper Plains.
- **Much of the Ohio River Valley experienced its wettest spring on record,** causing the Mississippi River to approach a 74-year high at Memphis, inflicting more than $6 billion in damage, and resulting in at least seven deaths.
- **New Jersey experienced its wettest month in its history** (August 2011), punctuated by heavy rains from Hurricane Irene that sent rivers to historic highs and damaged more than 2,000 homes.
- Chicago experienced its **third-biggest snowfall in history**, while much of the Northeast experienced its **heaviest October snowfall in at least two centuries**.

Some types of extreme weather events have become more common in recent years in the United States and worldwide, while science projects that global warming will likely fuel further changes in extreme weather in the years ahead.

- The United States has experienced an increase in heavy precipitation events, with the rainiest 1 percent of all storms delivering 20 percent more rain on average at the end of the 20th century than at the beginning. The trend toward extreme precipitation is projected to continue, even though higher temperatures and drier summers will likely also increase the risk of drought in between the rainy periods and for certain parts of the country.
- The United States has experienced an increase in the number of heat waves over the last half-century. Scientists project that heat waves and unusually hot seasons will likely become more common in a warming world.
- Hurricanes are expected to become more intense and bring greater amounts of rainfall, even though the number of hurricanes may remain the same or decrease.
- Global warming may also increase the danger posed by extreme weather events. Rising sea level, ecosystem changes, and changes in the form of precipitation could reduce the ability of natural and man-made systems to withstand even "normal" weather events.

The United States should reduce global warming pollution now, and begin planning for a future in which many types of extreme weather events are more severe and occur more frequently.

- **The United States – including federal, state and local governments – should adopt clean energy solutions that reduce our dependence on fossil fuels and reduce global warming pollution. Among the most important steps are:**
  - Adopting enforceable targets, financial incentives, regulatory changes, and investment strategies that increase the use of **renewable energy** sources such as wind and solar power.
  - Implementing appliance standards, building codes, enforceable efficiency targets for utilities, fuel-efficiency standards for vehicles and other steps to promote **energy efficiency**.
  - Continuing to develop and implement the **fuels and technologies of the future** – from electric vehicles to energy storage devices to "smart grid" technologies and new renewable sources of energy – through government support of research, development and deployment of those technologies and the adoption of technology-forcing standards where appropriate.
- Federal and state governments should **adopt and implement limits on global warming pollution** capable of reducing emissions by at least 35 percent below 2005 levels by 2020 and by at least 85 percent by 2050. These emission reductions are broadly consistent with what science tells us is necessary to lessen the most costly and devastating consequences of global warming.

- Short of economy-wide caps on global warming pollution, local, state and federal governments should **focus on capping and reducing pollution from the largest sources – most notably power plants and the transportation sector.** Regional programs such as the Northeast's Regional Greenhouse Gas Initiative can help to achieve this goal.
- Federal, state and local officials should take steps to better **protect the public from the impact of extreme weather events –** steps that save costs compared to suffering the full brunt of these extreme events. Government officials should explicitly factor the potential for global warming-induced changes in extreme weather patterns into the design of public infrastructure, revise policies that encourage construction in areas likely to be at risk of flooding in a warming climate, and continue to support research on the implications of global warming.

Introduction

It was the wettest of years. It was the driest of years.

If you lived in Cincinnati, Philadelphia or most places in between, the best word to describe 2011 was "wet." Both cities posted their wettest year in recorded history as part of a deluge of precipitation in the northern United States that triggered disastrous flooding of the Missouri, Mississippi and Susquehanna rivers – inundating portions of cities from Minot, ND, to Memphis, TN, to Binghamton, NY. So much precipitation fell that public officials were faced with the difficult decision of whether to deliberately swamp hundreds of square miles of farmland or put important cities along the Mississippi River at risk of catastrophic flooding.

While the north was being drenched, Texans were praying for rain. The Lone Star State endured its driest 12 month period in recorded history, while posting the hottest summer (June through August) ever recorded in a U.S. state – hotter even than the Dust Bowl summer of 1934. Just as 2011's floods devastated parts of the north, so did the 2011 drought devastate parts of Texas, ruining crops, sparking intense wildfires that destroyed property and claimed lives, and depleting water supplies.

If there was any year in U.S. weather history that defined the word "extreme," it was 2011. An incredible 56 percent of the country experienced either extremely wet or extremely dry conditions during the first 11 months of 2011.[2]

Last year's astonishing weather was a product of a naturally variable climate system that is increasingly influenced by human-caused global warming. Short-term phenomena – such as 2011's La Niña event – played a critical role in shaping the year's bizarre weather patterns, as they will likely continue to do in a warming world. But 2011 also provided a window into the future – one in which extreme downpours and record-breaking heat become increasingly frequent occurrences in the United States and worldwide as a result of global warming-induced shifts in the baseline conditions from which weather events emerge.

Global warming is already having an impact on extreme weather patterns and the impact is likely to continue and intensify in the years ahead. It is not too late, however, to prevent the very worst impacts of global warming from becoming reality. Nor is it too late to prepare ourselves and our communities for the changes that are already underway.

Science cannot tell us exactly how extreme weather will change in the years to come – particularly when it comes to complex weather events like hurricanes and tornadoes. But it is already telling us that change will come, and in fact, has already begun to arrive. The hardship and damage caused by weather-related disasters in 2011 should serve as a reminder of the stakes at play in the fight against global warming, and further motivate the United States to shift quickly away from polluting energy sources that put our climate and our health at risk.

Extreme Weather and Weather-Related Disasters

Strong scientific evidence suggests that certain types of extreme weather events will likely become more frequent and more severe as a result of global warming – potentially triggering an increase in the number and impact of weather-related disasters in the years to come.

Not every extreme weather event causes a disaster, however. Nor are all weather-related disasters caused by extreme weather events. To explore the links between global warming and weather-related disasters, it is first important to define our terms.

Defining Extreme Weather

The Intergovernmental Panel on Climate Change (IPCC), the world's leading scientific authority on climate change, has defined a "climate extreme" as follows:

> The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable.[3]

Weather or climate events are considered "extreme" ***in relation to a particular historical record at a particular location***. A storm that brings 12 inches of snow to Buffalo in January is not extreme. A storm that brings 12 inches of snow to Buffalo in early October – or 12 inches of snow to Washington, D.C., at any time of year – is extreme.

The IPCC's definition of "climate extreme" combines both weather events, which are of short duration, and climate events, which take place over a longer period of time.[4] In this report, we use the more common and colloquial term "extreme weather" as equivalent to the IPCC's definition of "climate extreme."

Why Extreme Weather Matters

Extreme weather events have the potential to inflict massive damage to human life, the environment and the economy. In some cases, these impacts are intense enough to be considered a "disaster." Other impacts may be less dramatic, but still significant. Impacts include:

- **Death and injury:** Extreme weather events cause significant loss of life in the United States each year. In 2010, for example, weather-related events killed 490 Americans.[5] The number of deaths is certain to have increased in 2011, with the deadliest weather disasters of the year – the tornado outbreaks of April and May 2011 – having resulted in more deaths than all of 2010's weather events combined.[6]
- **Permanent changes to ecosystems:** Extreme weather events can also result in permanent changes to ecosystems. The storm surge created by Hurricane Katrina, for example, permanently converted 118 square miles of wetlands and dry land along the Gulf Coast to open water.[7] The Chandeleur Islands off the Louisiana coast – part of the nation's second-oldest national wildlife refuge and an important bird habitat – lost 84 percent of their land area following Hurricane Katrina.[8]
- **Property and crop damage:** In 2011, total economic damages from the nation's 14 billion-dollar weather disasters exceeded $55 billion.[9] The many smaller, less catastrophic disasters around the country in 2011 imposed additional costs.
- **Emergency response expenses:** Deaths, injuries and property damage from extreme weather events would likely be even greater were it not for the work of emergency responders – firefighters, workers stacking sandbags alongside swollen creeks, and police and National Guard troops called upon to preserve public order. The costs of providing emergency response for extreme weather events are significant. The federal government alone, for example, spends approximately $1 billion per year on fire suppression efforts.[10]
- **Economic disruption:** Natural disasters also cause temporary economic disruptions by reducing productivity, rendering transportation systems and other types of infrastructure inoperable, and forcing workers and businesses to expend time and resources recovering from dislocation and property damage. The catastrophic 1993 Mississippi River floods, for example, disrupted east-west transportation for six weeks in the heart of the Midwest.[11]
- **Investments in preventive measures:** Another hidden cost of extreme weather is the added cost of building structures and settlements designed to withstand those extremes. Adoption of stronger building codes designed to ensure that buildings withstand high winds and floods, or relocation or fortification of public infrastructure such as roads and sewer systems, imposes major costs.
- **Broader and longer-term impacts:** The costs of extreme weather events can persist long after buildings are rebuilt and things are seemingly "back to normal." During a disaster, schools and health centers may close, and close-knit communities may be torn apart through relocation, all with long-term implications for health, human development and the economy.[12]

Extreme Weather 2011: Lower Mississippi River Floods

States affected: Ohio, Indiana, Illinois, Missouri, Tennessee, Arkansas, Mississippi, Louisiana

The spring of 2011 saw two damaging storm systems hit the Ohio River Valley, spawning tornado outbreaks and dropping heavy rains on the region. Cities up and down the Ohio Valley set monthly records for April rainfall, with Cincinnati breaking its previous April rainfall record by 38 percent.[13] All in all, the Ohio Valley experienced its wettest spring on record.[14]

The above-normal precipitation – combined with unusually high snowmelt from the upper Midwest – set up the conditions for massive flooding of the lower Mississippi River beneath its junction with the Ohio River.

Flooding forced the evacuation of the town of Cairo, Illinois, which sits at the junction of the Ohio and Mississippi rivers, with water levels along the Ohio River topping the record levels set during a 1937 flood.[15] To relieve the pressure on the town's flood control structures, officials blasted a hole in the Bird's Point levee in neighboring Missouri, inundating 200 square miles of farmland.[16]

At Memphis, the Mississippi River crested near a 74-year high, with flooding affecting as many as 3,000 homes.[17] In some areas, floodwaters forced tributaries of the Mississippi to run backwards. Damages in the Memphis area alone were estimated at greater than $750 million.[18]

Further downstream, with floodwaters threatening Baton Rouge and New Orleans, the Army Corps of Engineers was forced to open the gates of the Morganza Spillway for the first time in nearly four decades and only the second time ever. The opening of the gates relieved pressure on the Mississippi River, but at the expense of allowing water to pour into the Atchafalaya River basin, flooding marshes, farmland and homes.[19] Roughly 100,000 acres of farmland were flooded, while more than 1,300 homes were affected.[20] Ironically, the flooding – generated by precipitation that fell hundreds of miles away – came at a time when Louisiana itself, like neighboring Texas (see page 23), was locked in a severe drought.

All told, the floods imposed damages of between $6 billion and $9 billion and resulted in at least seven deaths.[21]

Photo: Marilee Caliendo, FEMA

Floodwaters inundated portions of Memphis and surrounding communities in May 2011 as the Mississippi River reached its highest crest in the area since 1937.

Extreme Weather and Disaster: Exploring the Connection

Science can tell us whether a given weather event is statistically "extreme," but not whether the impacts of that event amount to a "disaster." Determining if an extreme event caused a disaster depends greatly on the context in which it occurs.

Weather-Related Disasters: A Definition

The Stafford Act, which governs disaster response in the United States, defines a "major disaster" as "any natural catastrophe … or, regardless of cause, any fire, flood, or explosion … which in the determination of the President causes damage of sufficient severity and magnitude to warrant major disaster assistance …."[22]

In short, for an event to be a "disaster," three things must occur:

- It must ***cause damage***.
- It must "warrant … assistance"; that is, it must ***outstrip a community's immediate ability to cope***.
- It must be ***recognized*** as a disaster. While some have suggested quantifiable definitions for the term "disaster" based on the number of deaths, injuries or economic damage inflicted, the term remains inherently subjective.

It does not necessarily follow that an increase in extreme weather will result in a proportionate increase in weather-related disasters. A coastal city that installs a storm surge barrier, for example, is better able to weather a major storm without damage than another city with no such protections. A town that allows development in a floodplain will be more likely to experience a "disaster" than a town that prohibits such development, even if the objective conditions facing the two towns are the same. Temperatures over 100° F caused massive loss of life in Europe in 2003 but not in Texas in 2011 because air conditioning is common in Texas and rare in Europe. And a Category 5 hurricane that tracks offshore is far less likely to cause damage than one that makes a direct hit on the coast.

Comparing changes in the number or severity of weather-related disasters, therefore, is unlikely to yield much useful information about trends in extreme weather events. However, an understanding of the frequency and impact of extreme weather is essential in order to develop a realistic understanding of the trade-offs involved in allowing global warming – with its likely impact on precipitation and temperature extremes – to continue unchecked.

In this report, we define "weather-related" disasters as presidentially declared major disasters in categories with a plausible connection to weather or climate events. For example, we consider wildfires to be "weather-related" disasters even if they were started deliberately or accidentally by humans, because few forest fires rise to the level of disasters without the proper weather or climate conditions to fuel their spread.

As will be discussed in greater detail below, global warming is likely to bring about changes in the timing, severity and number of extreme weather events. All other things being equal, more frequent or more severe extreme weather events will *tend* to lead to more frequent and more severe weather-related disasters. But the degree to which that transpires – if at all – depends on where the extreme weather events occur as well as the degree of flexibility and resilience built in to the ecosystems and human infrastructure of a community and the resources that community possesses to respond when extreme weather strikes.

Global Warming and the Future of Extreme Weather

An extreme weather event triggers a disaster when it causes damage that outstrips a community's ability to cope. Global warming is likely to increase the risk of weather-related disasters in two ways: first by producing more extreme events that overwhelm our existing systems, and second by diminishing the ability of natural or man-made systems to withstand extreme weather events, increasing the amount of damage they cause.

In November 2011, the Intergovernmental Panel on Climate Change (IPCC) – the world's leading scientific authority on climate change – issued a special report on extreme weather. The report summarized the clear scientific agreement about the links between global warming and future changes in certain types of extreme weather events, even as it acknowledged the uncertainty of future trends in other types of events.

The report found that global warming is already shifting patterns of extreme weather worldwide, judging it "likely" (see "Definitions of IPCC Uncertainty Terms," next page) that human-driven changes have already led to higher daily high and low temperatures and expressing medium confidence that climate change has led to the intensification of extreme precipitation.[23]

Definitions of IPCC Uncertainty Terms

The Intergovernmental Panel on Climate Change uses specific terms to convey the probability that its conclusions are correct based on the current level of progress in climate science. Terms such as "likely" and "very likely," therefore, have specific meanings. As defined in the IPCC's 2011 report on extreme weather events:

- Statements defined as *virtually certain* have a 99 to 100 percent probability of being correct.
- Statements defined as *very likely* have a 90 to 100 percent probability of being correct.
- Statements defined as *likely* have a 66 to 100 percent probability of being correct.[24]

Each of these measures of probability incorporates an assessment of the **confidence** with which scientists have reached their conclusion. In some cases, the scientists who authored the IPCC report may have lower degrees of confidence in the validity of a particular finding, leading (for example) to an assertion of "medium confidence" in a particular conclusion. Unlike the IPCC's definitions of uncertainty, its declarations of confidence are qualitative rather than quantitative.[25]

The IPCC projected that future changes in extreme weather could occur as the world continues to warm. Specifically:

- It is virtually certain that extremely hot days will become both hotter and more frequent over the course of the next century.
- It is very likely that heat waves will become longer, more frequent or more intense over most land areas of the globe.
- It is likely that heavy precipitation events will occur more frequently in many areas of the world or that the proportion of total rainfall that occurs in the form of heavy rain events will increase.
- It is likely that heavy rainfalls associated with tropical cyclones will increase and that the average maximum wind speed will increase.
- There is medium confidence that droughts will become more intense, including in central North America.[26]

There is currently little confidence in future projections of the impact of global warming on events such as tornadoes. In part, this is because global climate models have difficulty predicting small-scale weather phenomena. It is also because there are multiple factors involved in the formation of tornadoes and similar events, all of which will be affected by global warming, with the interactions among those factors difficult to predict.

Extreme Weather 2011: Upper Plains and Missouri River Floods

States affected: Idaho, Montana, Wyoming, North Dakota, South Dakota, Minnesota, Nebraska, Iowa, Kansas, Missouri

The spring of 2011 saw extreme precipitation throughout the northwestern United States. In the Columbia River basin of the Pacific Northwest, the level of snowpack remaining on May 1 was nearly double the historical average.[27] And at Donner Pass in California's Sierra Nevada, 94 inches of snow remained on the ground by early June, shattering the previous record.[28]

The impact of the heavy precipitation, however, was greatest in the upper Plains. Wyoming experienced its wettest spring in more than 100 years of record-keeping, while other nearby states experienced precipitation levels well above normal.[29] As snow began to melt in late spring, flood conditions quickly arose along the Missouri River, its tributaries, and neighboring rivers, destroying cropland, ruining infrastructure, inflicting billions of dollars of property damage, and costing at least five lives.[30]

In Montana, floodwaters isolated portions of the Crow Indian Reservation from the outside world and complicated cleanup of a massive oil spill from a ruptured ExxonMobil pipeline, with high waters along the Yellowstone River allowing oil from the spill to contaminate nearby farmland.[31]

In North Dakota, the Souris River flooded the city of Minot, overwhelming a flood control system that had been built in the 1970s and designed to contain a 100-year flood.[32] More than 4,000 homes in Minot were flooded.[33] The disaster even forced the cancellation of the North Dakota State Fair.

June 2011 saw the Missouri River post its all-time record for runoff for the section of the river above Sioux City, Iowa, with the months of May and July ranking third and fifth all-time, respectively.[34] At one point in the year, the Missouri River was in flood stage in every state it passed through.[35] Unsurprisingly, the swollen Missouri taxed the region's network of levees and dams, causing several levees to give way and inflicting as much as $1 billion worth of damage to the region's flood control system.[36]

Dams and levees weren't the only pieces of infrastructure to be harmed. At one point in June, all bridges across the Missouri along a 100-mile stretch of the river were closed due to flooding. Floodwaters "virtually obliterated" several miles of Interstate 680 between Council Bluffs, Iowa, and Omaha, Nebraska, and damaged many other major and minor roads.[37] Floodwaters invaded the site of the Fort Calhoun nuclear power plant, forcing the temporary cutoff of off-site electrical power to the plant, which remained off-line as of the beginning of 2012.[38]

Damage to agriculture was extensive, with the flood estimated to have affected approximately 450 square miles of farmland.[39] The value of crop losses in western Iowa alone was estimated at $200 million.[40] The Iowa Department of Natural Resources estimated that nearly 1 million trees could eventually die as a result of the floods.[41] Damage from the floods is likely to top $2 billion in all.[42]

Photo: Patsy Lynch, FEMA

Floodwaters from the Souris River inundated much of Minot, North Dakota, overwhelming flood control structures designed to protect against a "100-year" flood.

Extreme Weather Is Already Changing and Is Likely to Change Further

Changes in extreme weather patterns have already been detected in the United States, while climate science suggests that future changes will likely be in store.

Heavy Rain and Snow

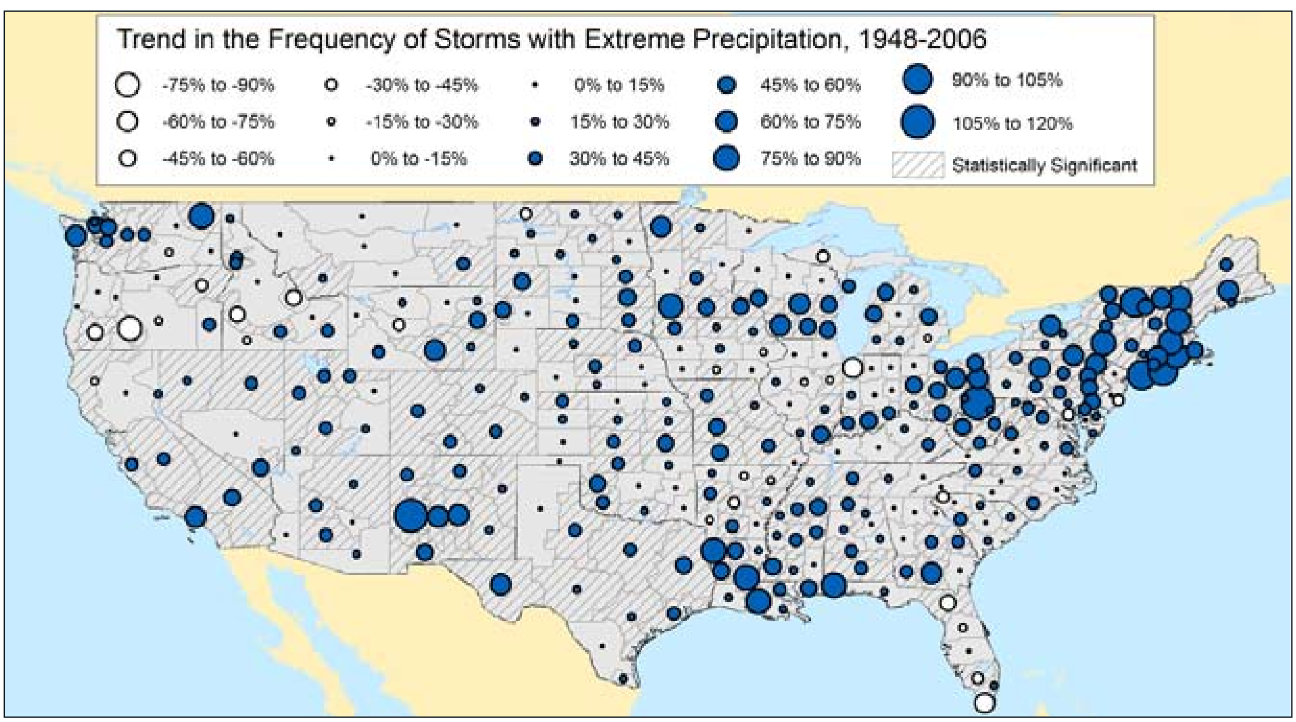
The United States is receiving more of its precipitation in the form of heavy rain and snow events. Scientists have linked the observed increase in heavy precipitation events in the Northern Hemisphere to global warming pollution and expect that the trend will likely continue in a warming world.[43]

Over the last century, the amount of precipitation falling over most of the United States has increased, except for the Southwest.[44] The extra rain and snow, however, has tended to fall during heavy precipitation events. Research suggests that there has either been no change or a decrease in the number of light or average precipitation days in the U.S. during the last 30 years.[45] The amount of precipitation falling in the top 1 percent of rainfall events, however, has increased by an average of 20 percent over the course of the 20th century.[46]

A 2007 Environment America Research & Policy Center analysis found that the number of extreme precipitation events had increased by 24 percent over the continental United States between 1948 and 2006, with the greatest increases coming in New England (61 percent) and the Mid-Atlantic region (42 percent).[47] (See Figure 1.)

The changing patterns of heavy precipitation have the potential to contribute

Figure 1. Trend in Frequency of Storms with Extreme Precipitation, 1948-2006[48]



Return Time (e.g., The "100-Year Flood"): Its Meaning and Significance

Many engineering and planning decisions are made on assumptions about the likely "return time" of extreme weather events. Calculations of return time are typically based on the historical climate record and rest on the assumption that what has happened in the past provides us with useful information about the future.

Terms such as "100-year flood" are commonly misunderstood to suggest that such an event occurs only "once every 100 years." The proper way to interpret return time is as an estimate of the probability of an event occurring in any given year, *based on the historical climate record*. In other words, a 100-year flood would have an estimated 1 percent chance of occurring in any particular year. The occurrence of 100-year events in back-to-back years would be improbable, but not impossible.

Because the climate is changing, the historical climate record may no longer be as useful in helping society to estimate how frequently extreme events will occur in the future. In addition, as the climate changes, the definition of a "100-year flood" itself will likely change in some places as the climate record comes to incorporate the more severe flooding events that could result from global warming-induced shifts in precipitation patterns.

In this report, we make use of terms such as "100-year flood" to illustrate the improbability of specific extreme weather events in the context of the historic climate record, but caution readers that what may have been judged to be a "100-year flood" based on historical climate records may now – depending on the changes that have taken place in the climate in that location – be more or less likely to occur.

to flooding that claims lives and damages ecosystems and property. They also have major repercussions for infrastructure planning and emergency response. Key decisions about settlement patterns and infrastructure design are based on the expected "return time" of large rain and snow events – for example, "100-year" storms. (See "Return Time: Its Meaning and Significance," above.)

The return time of extreme rainfall events is already changing, as is the amount of rain falling during the most extreme events. Across the United States, the amount of rainfall expected in 2-year, 5-year and 10-year rainfall events has increased, with the most significant changes in the Northeast, western Great Lakes, and Pacific Northwest regions.[49] In much of the northeastern United States, a storm that would have been expected to occur once every 50 years based on data from 1950-1979 would be expected to occur once every 40 years based on data from the 1950-2007 period.[50] The trend toward more days of heavy precipitation has even held true in the Southwest, which has experienced less precipitation overall.[51]

The same conditions that lead to more intense rainstorms in a warming world – including increased evaporation and the ability of warmer air to hold more water vapor – can also be expected to contribute to an increase in extreme snowstorms in places where it remains cold enough to snow. Indeed, a study of snowstorms during the 20th century found that most snowstorms occurred during *warmer*-than-normal years in most of the United

States.[52] Global warming can be expected to increase the "lake effect" snowfalls common in the Great Lakes region – at least for a time – as warmer temperatures reduce ice cover on the lakes, enabling the exposed water to contribute more moisture to winter storms. A 2003 study found that there had been a significant increase in snowfall at sites receiving lake-effect snow since the early 1930s, compared with no trend for comparable areas not receiving lake-effect snow.[53]

The greatest increase in intense precipitation is projected for the Northeast

Photo: NOAA/NASA GOES Project

Snow fell in 30 U.S. states during the massive Groundhog Day Blizzard in 2011. This satellite image shows the extent of the snowfall, which ranked as the third-largest snowstorm in Chicago's history.

Extreme Weather 2011: Groundhog Day Blizzard

States affected: New Mexico, Oklahoma, Missouri, Illinois, Wisconsin (declared disasters)

In late January and early February, a massive winter storm roared through the nation's midsection and Northeast, depositing snow, sleet and ice across a broad swath of the United States from New Mexico to Maine.

The greatest impacts from the storm were felt in the Chicago area, which received 20 inches of snow, making it the city's third-largest snowstorm on record. Coupled with ferocious winds, which reached 70 miles per hour along the Chicago lakefront, the blizzard paralyzed traffic along Lake Shore Drive – stranding roughly 1,500 vehicles and their occupants in the cold and wind – and piled up two to five foot drifts throughout the city.[56]

Chicago may have been in the bull's eye, but it was not the only area affected. Ten or more inches of snow fell in an area stretching from northeastern Oklahoma to Michigan to northern New England.[57] Sleet and freezing rain caused dangerous icing conditions in other parts of the country. As much as three-eighths of an inch of ice accumulated in parts of south Texas near Corpus Christi.[58] The Texas border region experienced its coldest temperatures in decades, with even portions of Mexico receiving a dusting of snow.[59] The cold temperatures in the wake of the storm caused malfunctions at several fossil fuel-fired power plants in Texas, triggering rolling blackouts.[60]

All in all, the storm caused approximately $1.8 billion in damage and caused 36 deaths, many of them attributable to automobile accidents or snow shoveling.[61] The event led to disaster declarations affecting 169 counties housing more than 16 million people in five states.[62]

and Midwest.[54] In addition, hurricanes and other coastal storms are expected to pack more precipitation – even though there is little clarity over whether the number of those storms is expected to increase or decline.[55]

Heat, Drought and Wildfire

In 2011, the northern and southern United States experienced very different weather extremes, with flooding in the upper Midwest and exceptional drought in Texas. As a Canadian climate scientist told the Associated Press in describing the rash of extreme weather in North America during 2011, "Too little water in the South, too much in the North. It's a story we're hearing more and more often."[63]

Among the paradoxes of a warming world is the potential for the United States to experience both more extreme rainstorms *and* more frequent drought caused by extended dry spells and higher temperatures.

There has been a documented increase in the number of heat waves in the United States since 1960.[64] Unlike an earlier period of extreme heat, the Dust Bowl 1930s, recent heat waves have come with marked increases in nighttime temperatures – indeed, the share of the United States experiencing hotter nighttime low temperatures is greater than the share experiencing hotter daytime temperatures.[65] The trend in rising nighttime temperatures has been particularly marked along the Pacific coast, and in parts of the Southwest and northern Rockies.[66]

Parts of the country are also experiencing more and longer dry spells in between precipitation events. Prolonged dry spells – periods of little rain lasting a month or longer in the eastern United States and two months or longer in the Southwest – are occurring more frequently, with the projected period between such episodes shrinking from 15 years to 6-7 years in the eastern United States.[67] Hot and dry conditions – particularly when present for a long period of time – lead to drought. During the second half of the 20th century, drought became more common in parts of the northern Rockies, the Southwest and the Southeast, and less common in parts of the northern Plains and Northeast.[68]

In parts of the United States, especially the West, water scarcity can be caused not only by a lack of rain, but also by changes in the share of precipitation that falls as rain versus snow and the timing of snowmelt. Western states often rely on melting mountain snowpack to supply human and agricultural needs during the long dry season. With the notable exception of 2011 – which brought record mountain snowpack to parts of the West – there has been a significant reduction in snowpack in recent years, with earlier melting and earlier peak streamflows in much of the West.[69] The recent decline in snowpack in the Mountain West has been found to be nearly unprecedented over the last millennium, caused by unusual springtime warming reinforced by climate change.[70] As snowpack declines even further, large parts of the West could find themselves under severe water stress.[71]

These trends are expected to continue and intensify in a warming world. Heat waves are projected to be more frequent, more intense, and last longer, with climate models projecting that the entire contiguous United States will likely experience a significant increase in the number of extreme heat days by the end of the century under a scenario in which global warming pollution continues unabated.[72] By the end of the century, parts of the nation, particularly in the West, may experience a once-in-20-years heat event (based on the historical record) as frequently as once every other year.[73]

Heat waves and unusually hot seasons are also projected to become more common. Research projects that seasons as hot as the hottest on record for the second half of the 20th century could occur four to seven times per decade by the 2030s in much of the United States.[74]

Hotter temperatures bring with them numerous threats to public health. High temperatures – along with sunlight, nitrogen oxides and volatile organic compounds – are necessary for the creation of ozone "smog," which damages the respiratory system, reduces lung function, and aggravates asthma and other respiratory diseases.[75] As more days each year meet the threshold for smog formation, the number of smoggy days could increase, assuming that the amount of smog-forming pollution emitted from cars, factories and other sources remains the same. The Union of Concerned Scientists estimates that, by 2020, the United States could experience more than 900,000 additional missed days of school, and more than 5,000 additional hospitalizations of infants and seniors due to the additional exposure to ozone smog resulting from higher temperatures caused by global warming.[76]

Nor is air pollution the only health threat posed by more extreme temperatures. Global warming can be expected to increase the number of deaths caused by heat stress (though the impact may be offset somewhat by a corresponding decline in cold-related deaths).[77] Higher temperatures may also change the patterns of occurrence of various infectious diseases. A 2009 study, for example, found a correlation between warmer temperatures and increased reports of infection by West Nile Virus.[78]

Extreme heat, coupled with longer dry spells and an expected decline in summer precipitation across most of the United States, could contribute to increased risk of drought. Climate models project that nearly the entire lower 48 states could experience more dry days by the end of the century, with strong agreement among the models across most of the country.[79]

Climate models are in strong agreement that the Southwest will likely receive less annual precipitation, with significant reductions in soil moisture – primarily from increasing evapotranspiration – over the course of this century.[80] The Southwest is already prone to drought. In fact, research into the long-term weather history of the western United States suggests that the first half of the 20th century – the period during which intense settlement of the area began – was actually an anomalously *wet* period in the region's history.[81]

Higher temperatures, prolonged dry spells, and drought are also expected to contribute to an increase in wildfire activity in parts of the country.

One recent modeling effort projected that California would experience a 12 to 53 percent increase in the probability of large fires by the 2070-2099 timeframe under several scenarios of future climate change.[82] Global warming may also change the way that fires behave once started. A 2005 study for the state of California found that fires in one area of Northern California could be expected to spread more quickly under a climate change scenario, leading to a potential increase in the number of fires that escape initial efforts at containment.[83] (The changes that global warming will impose on western forests are complex and multifaceted, however. In some pockets of the West, global warming could result in reduced fire risk, as a reduction in moisture inhibits plant growth, reducing the availability of fuel.[84])

The risk of damaging wildfires extends beyond the West.[85] One recent modeling exercise found that fire potential could increase across the country, with the potential for fires moving from "low" to "moderate" in the southeastern and northwestern United States, and fire potential increasing in the Northeast and Southwest as well.[86]

Extreme Weather 2011: Texas Drought and Wildfires

States affected: Texas (disasters declared as a result of wildfire)

The state of Texas experienced one of its worst droughts in history during 2011. At its peak in October, nearly 97 percent of the state was in a state of extreme or exceptional drought.[87]

The 12 months from October 2010 to September 2011 were the driest on record for Texas since record-keeping began in the late 19th century.[88] At the same time, Texas experienced not only the hottest June through August in its history – with an average temperature of nearly 87 degrees – but also the hottest three-month period of any U.S. state in the historical record, beating out Oklahoma's Dust Bowl summer of 1934 by an incredible 1.6 degrees.[89] Neighboring Louisiana, Oklahoma and New Mexico also experienced their hottest summers on record.[90]

The extreme heat, especially when combined with humidity to create extremely high heat index conditions, put the health of vulnerable people in jeopardy. More than 20 people in Texas and Oklahoma perished from extreme heat.[91] At least six high school football players and one coach died throughout the southern United States during the summer of 2011 – most of them following early-season workouts conducted in extreme heat.[92] It was believed to be the worst summer for deaths among high school football players in nearly four decades.[93] Hot, humid conditions have been associated with many of the 58 heat-related deaths of football players between 1980 and 2009.[94]

The hot, dry weather contributed to Texas' worst wildfire season in history, with fires tearing through nearly 4 million acres of land, destroying more than 2,900 homes and killing 10 people.[95] The wildfires led to major disaster declarations in 52 counties in Texas that are home to more than 566,000 people.[96] Texas Forest Service Director Tom Boguss told the (Fort Worth) *Star-Telegram* that "[w]e had fuel so historically dry that it made fire behavior very intense … We had things happening that people who were in the fire business for 50 years said that they had never seen."[97] Damage from the fires was estimated at roughly a half-billion dollars.[98]

Even greater economic damage was done to Texas' agriculture industry. As of mid-August, crop and livestock losses from the drought were estimated at greater than $5 billion, a figure that has likely since been exceeded.[99]

The drought affected other aspects of life in Texas, as well. In October, a massive dust storm reminiscent of the Dust Bowl hit the city of Lubbock, dropping visibility to zero and paralyzing traffic.[100] For the second year running, a ban on outdoor fires caused the cancellation of the traditional bonfire at Texas A&M University prior to its football rivalry game with the University of Texas.[101] Electric utilities and public officials were concerned that continued dry conditions could force the shutdown of power plants that rely on water for cooling, jeopardizing the stability of the state's electric grid.[102] Historic preservation advocates were preparing for the exposure of previously submerged shipwrecks, gravesites and other historic artifacts as water levels at the state's lakes continued to drop.[103] And, as of late November, the city of Groesbeck – home to 6,500 people – warned that it was weeks away from running out of water entirely.[104]

Photo: Patsy Lynch, FEMA

Residents of Bastrop, Texas, clean up debris from the intense wildfires that struck the area in early September 2011.

Hurricanes and Other Coastal Storms

Hurricanes have become more powerful in recent years – a trend that could continue in a warming world. However, there remains much uncertainty about how global warming will affect the number of hurricanes.

There has been an observed increase in the number of Category 4 and 5 hurricanes in the Atlantic Ocean since 1980.[105] Measurements that aggregate the destructive power of tropical storms – in terms of their intensity, duration and frequency – over entire storm seasons have shown a marked increase in the power of hurricanes in the Atlantic since the 1970s.[106] Other research has found that both the energy of and amount of precipitation in tropical cyclones in the Atlantic has increased in recent years, with an abrupt, step-wise increase in cyclone energy and precipitation occurring in the mid-1990s.[107]

An expert team convened by the World Meteorological Organization (WMO) concluded in 2010 that hurricane activity could change in important ways by the end of this century if global warming continues unabated:

- The number of tropical cyclones is projected to decrease globally, by an estimated 6 to 34 percent, but with great potential variation in trends for specific ocean basins.
- Average maximum wind speeds are projected to increase globally by 2 to 11 percent.
- The number of intense hurricanes is projected to increase.[108]
- Tropical cyclones are projected to bring more rainfall, with a projected average increase of about 20 percent.[109]

These global trends are likely to vary by region. Five of seven climate models in one recent study pointed to an increase in the aggregate power of hurricanes in the Atlantic by the end of the next century, with an average increase in power across all models of 10 percent.[110] Another recent modeling effort projected that the number of severe Category 4 and 5 hurricanes could be expected to double in the Atlantic over the course of the 21st century as a result of global warming.[111]

Recent research by scientists at the Massachusetts Institute of Technology suggests that global warming could increase the amount of property damage caused by hurricanes along the Atlantic Coast in upcoming decades – though, notably, the study did not factor in the impacts of higher sea levels or freshwater flooding from increased precipitation, which was the source of much of the damage caused by 2011's tropical storms.[112] Moreover, the long-standing trend toward increasing development of coastal areas suggests that hurricane damages may continue to increase even if there is little to no change in hurricane frequency or severity.

Residents of the West Coast do not generally have to be concerned with hurricanes, but they do experience intense winter storms. In the last two years, the western United States has experienced two epic winter storms. A storm in 2010 set all-time records for low atmospheric pressure across a broad section of the Southwest, bringing with it snow, flooding, hail, tornadoes and heavy winds.[126] And in 2011, Alaska was hit with a massive winter storm that brought hurricane-force winds, snow and storm surge flooding to a large portion of the state.[127]

Parts of the Pacific Ocean off the U.S. West Coast have experienced increasing numbers of intense winter storms since the middle of the 20th century.[128] One clue to the increase in the power of winter

Extreme Weather 2011: Hurricane Irene

States affected: North Carolina, Maryland, Virginia, Delaware, New Jersey, Pennsylvania, New York, Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, Maine

As Hurricane Irene barreled up the East Coast in August 2011, public officials braced for a potential nightmare scenario: a strong hurricane making a direct hit on New York City. New Yorkers prepared for wide-scale wind damage and storm surge flooding, with city officials taking the unprecedented step of closing down the city's subway system.

As it turned out, New York City was spared Irene's worst. But other areas were not nearly as lucky.

Throughout the East, 45 people died as a result of the storm.[113] Major disasters were declared for 218 counties in 13 states housing more than 46.6 million people.[114] More than 7 million people in the affected area lost power during the storm.[115]

But it was Irene's massive size and intense rains – rather than its winds or storm surge – that caused the greatest damage. Portions of North Carolina, for example, received as much as 20 inches of rain from the storm.[116] The massive rains came on top of near-record August rains along much of the East Coast, setting the stage for destructive floods.

Credit: Wendell Davis, FEMA

Flooding rains from Hurricane Irene destroyed roads and bridges throughout Vermont. The historic Bowers covered bridge (above), built in 1919, was lifted off its abutments and carried 200 feet downstream.

In northern New Jersey, several rivers hit record levels, flooding numerous towns and causing major damage to more than 2,000 homes.[117] Irene's rains put August 2011 over the top to become the wettest month in New Jersey since at least 1895 – surpassing the previous monthly record for rainfall by nearly 40 percent.[118]

In Vermont, the floods unleashed by Irene's soaking rains amounted to the state's second-worst natural disaster since 1900.[119] Parts of Vermont received up to 11 inches of rain, with 4-8 inches common across the state.[120] The heaviest rainfall amounts were in the mountains, and because the rains fell on already saturated soil, the result was roaring flash floods that wiped out key infrastructure across the state.[121]

Rivers in parts of Vermont surpassed their record flood levels – some of them by several feet. Approximately 260 roads, 33 bridges and the state's main rail lines were closed due to flood damage or downed limbs. Residents of 13 towns were cut off from the outside world – some for several days – as roads and bridges were washed away.[122] The National Guard was forced to use helicopters to bring supplies to residents of towns cut off by floodwaters, including the resort town of Killington, where 400 visitors and staff were left stranded.[123]

In the city of Rutland, the supervisor of the city's water treatment plant and his son were killed when they were swept away by rising waters while checking the plant's intake valves.[124] Approximately $500 million in damage was done to state highways in Vermont alone.[125]

Overall, Hurricane Irene caused an estimated $7.3 billion in damage.

storms has come from the measurement of wave heights off the coast of the Pacific Northwest. Researchers have found that waves off the Oregon coast are higher than they were 35 years ago, with the greatest increase coming in the largest waves.[129] As recently as the early 1990s, scientists estimated that the height of a "100-year wave" (one expected to occur only once every century) was 33 feet; now it is estimated to be 46 feet.[130] The study also found that the increases in wave height have been greatest off the coast of Washington and northern Oregon, and less in southern Oregon. The study is consistent with other research that suggests an increase in the height of the highest waves along the West Coast, particularly in the Pacific Northwest.[131]

There is less clarity regarding the potential impacts of global warming on extratropical storms – storms that exist in the mid-latitudes, as opposed to the tropics, such as the "Nor'easters" that are common along the East Coast. Recent studies suggest that global warming could reduce the total number of extratropical cyclones in the Northern Hemisphere – consistent with the already-falling number of these storms as shown by the historical data.[132] The U.S. Climate Change Science Program, however, concluded that the number of *strong* extratropical storms in the Northern Hemisphere could increase.[133] Other research, however, suggests that there may be no intensification of extratropical storms on the whole.[134]

One clear conclusion of the research is that extratropical storms – like tropical storms – are likely to deliver increased precipitation, leading to increased potential for flooding rains and major snowfall (see page 18).[135]

Global Warming Could Increase the Destructive Potential of Weather Events

In addition to its potential to increase the number or severity of extreme weather events, global warming will likely also lead to changes that could make extreme weather events – and even some routine events – more destructive, increasing the potential for disaster.

Sea Level Rise

It is hard to overestimate the importance of America's coasts to the nation. More than half of all Americans (52 percent) live in coastal counties (including those surrounding the Great Lakes).[136] Seven of America's 10 largest metropolitan areas – including world centers of government, finance and culture – sit along the coastlines or along tidally influenced rivers.[137] Critical highways, airports, seaports and rail lines all sit in close proximity to coastal waters.

Global warming has already begun to accelerate the rise in sea level and is projected to lead to even greater increases in the years to come. Sea level has risen by nearly 8 inches (20 cm) globally since 1870, with the rate of sea level rise increasing in recent years. Sea level rise is occurring both because of the thermal expansion of sea water as it warms and because of the melting of glaciers and ice caps.[138]

Sea level rise is not experienced the same way at all points along the coastline. Land along the coast is rising or falling as a result of long-term geological processes (and, in some cases, such as along the Gulf Coast, by the drawdown of underground reserves of fossil fuels or fresh water). In addition, global warming is likely to cause sea level to rise more in some locations than others, due to associated changes in ocean circulation patterns.

Figure 2 shows the relative rise in average sea level at various points along the U.S. coast from the beginning of record-keeping at each station to 2006. Relative sea level rise has been greatest in areas that are experiencing simultaneous land subsidence, such as in the Mid-Atlantic and along the Gulf Coast. The combination of land subsidence and rising seas has contributed to the loss of 1,900 square miles of coastal wetlands in Louisiana.[139]

Global warming will likely bring higher seas as glaciers and ice caps melt and sea water continues to expand as it warms. In 2007, the Intergovernmental Panel on Climate Change estimated that sea level could rise by 7 to 23 inches (18 to 59 centimeters) by the end of the century. That estimate, however, (as the IPCC acknowledged at the time) did not include the potential for sea level change resulting from the potential changes in the flow of ice sheets in Greenland or Antarctica.[141]

Research conducted since publication of the IPCC's Fourth Assessment projects that sea level rise could be significantly greater than the IPCC estimate. One recent study projects that sea level rise by the end of the century could be more than double that predicted by the IPCC – or between 2.5 and 6.25 feet (75 centimeters and 1.9 meters).[142]

What would such an increase mean for America's coastline? In the Mid-Atlantic region from New York to North Carolina, approximately 1,065 square miles of dry land, as well as vast areas of wetland, are less than 3.3 feet (1 meter) above the

Figure 2. Measured Rise in Mean Sea Level Along the U.S. Coast (from the beginning of record-keeping at each station to 2006) in Feet per Century[140]

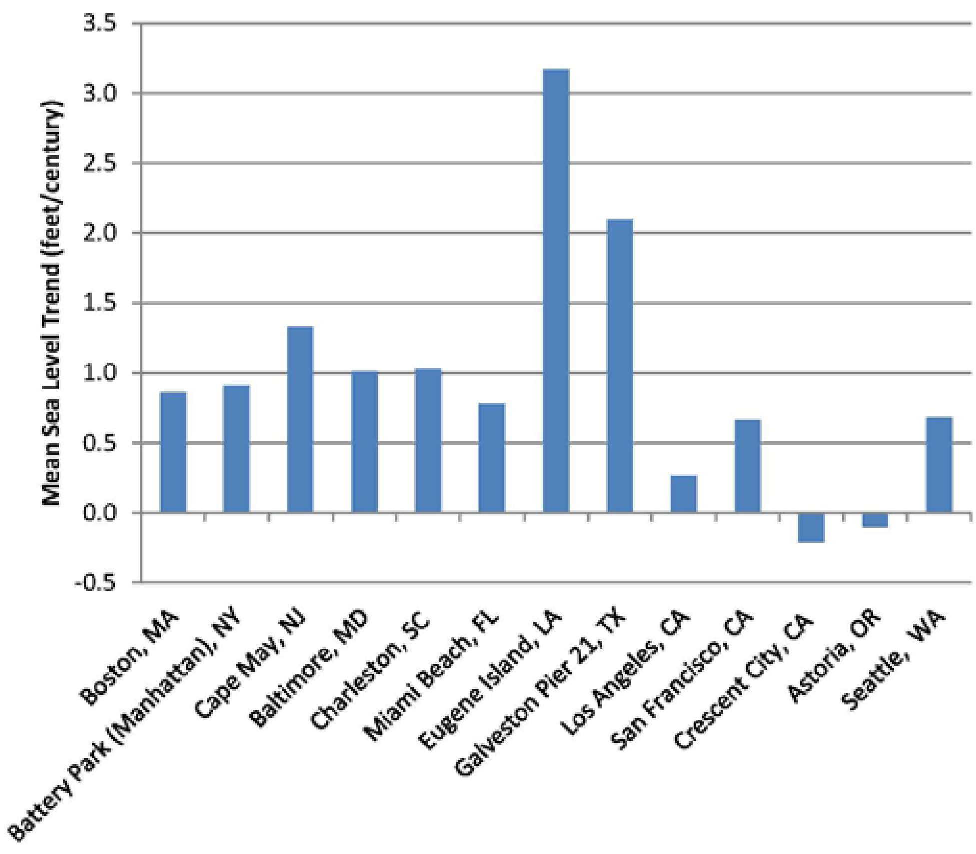


Table 1. Land Area Less than One Meter in Elevation Above Spring High Water, Mid-Atlantic Region (sq. mi.)

	NY	NJ	PA	DE	MD	DC	VA	NC	TOTAL
Dry Land	63	106	9	49	174	2	135	528	1,065
Non-Tidal Wetland	4	66	1	12	47	0	57	1,193	1,381
All Land	91	551	13	199	652	2	817	2,212	4,536

spring high water mark. (See Table 1.)[143]

While many of these areas will be at risk of inundation, rising sea level will also increase the destructive power of coastal storms by driving storm surge further inland. Under a high-emission scenario, a "100-year" coastal flood in New York City (a flood of a size expected to occur once a century based on historical records), could happen twice as often by the middle of this century, and 10 times as often by the end of the century.[144]

In the portion of the Gulf Coast stretching from Galveston, Texas, to Mobile, Alabama, more than half of the highways, nearly half of the rail miles, 29 airports and almost all port infrastructure will be vulnerable to flooding in the future due to the combination of higher sea level and hurricane storm surge. Much of this infrastructure is at risk even in the absence of storm surge due to projected sea level rise.[145]

In the Mid-Atlantic region, a one-meter sea level rise could result in the breakup or migration of barrier islands, and convert vast areas of wetland to open water. In areas like the New York City metropolitan area, sea level rise coupled with storm surge from coastal storms could result in severe damage to transportation infrastructure, including airports, highways, tunnels, railroads, ports and public transportation systems.

Making matters worse for residents of the northeastern United States is evidence suggesting that sea level rise in that region could be greater than the global average, due to global warming-induced changes in ocean circulation patterns. The result could be an additional 8 inches of sea level rise in cities such as Boston, New York and Washington, D.C., atop the roughly three feet that could occur globally, further magnifying the damage caused by even routine coastal storms.[146]

Changes in the Type of Precipitation

As described above, global warming is anticipated to make precipitation – whether it comes in the form of rain or snow – more intense. However, as the world continues to warm, a greater share of precipitation in some parts of the country is expected to fall in the form of rain, rather than snow.[154] That shift could mean trouble for areas – particularly the West – that currently rely on snowpack to store water for gradual release during the spring months.

A good example of the complicated connections between precipitation and flooding is the Columbia River basin of Washington and Oregon. Climate science projects that spring snowmelt will

Extreme Weather 2011: Tornado Outbreaks

States affected: Kansas, Oklahoma, Arkansas, Missouri, Iowa, Minnesota, Mississippi, Alabama, Georgia, Tennessee, North Carolina, Kentucky, Indiana, Ohio, New York (states with declared disasters related to tornadoes in April and May 2011)

There is little consensus among scientists about the effect that global warming will have on small-scale weather phenomena like tornadoes. But the most devastating weather-related disasters of 2011 – at least in terms of loss of life – resulted from an historic outbreak of tornadoes that swept through parts of the South and Midwest during the spring.

April 2011 was the most active month on record for tornadoes in the United States since record-keeping began. The 753 tornadoes recorded in April were nearly triple the previous April record.[147] On April 27, a tornado ripped through Tuscaloosa, Alabama, killing 78 people and destroying 12 percent of the city, including more than 1,200 homes.[148] Taken together, the April tornadoes killed more than 300 people and inflicted more than $10 billion in damage.[149]

Credit: Elissa Jun, FEMA

The intensive care unit at St. John's Regional Medical Center in Joplin, Missouri, was damaged in the massive EF-5 tornado that killed 170 people in the area in May. Damage to the hospital was so extensive that it will need to be rebuilt.

Less than four weeks later, a category EF-5 tornado (the strongest possible) packing winds in excess of 200 miles per hour touched down in Joplin, Missouri. The tornado blew out windows on three sides of St. John's Regional Medical Center, where five people died, and leveled homes, businesses and apartment buildings.[150] Another 11 people perished at a nursing home struck by the storm.[151] A National Weather Service report described the destruction:

> Numerous, over 15,000, vehicles of various sizes and weight including buses, tractor trailers and vans were tossed over 200 yards to several blocks, and some being crushed or rolled beyond recognition. … Main steel roof support trusses were rolled like paper, and main support beams twisted or curved. [I]t was very common to find various size boards, limbs, and even small twigs and leaves embedded into wood and stucco walls. In some cases, even cardboard was embedded sideways into stucco walls.[152]

A total of 160 people lost their lives in the storm, making the Joplin tornado the deadliest in the United States since reliable record-keeping began in 1950. The Joplin tornado, along with other tornadoes that raked the Midwest during the May outbreak, inflicted more than $9 billion in damage.[153]

likely occur earlier in the Pacific Northwest, while precipitation could increase in the winter but decrease during the summer.[155] The result is projected to be a shift toward higher river flows during the winter and spring months.[156] A 2008 study of the potential for flooding in major river basins worldwide under an extreme climate change scenario projected that the Columbia River could experience what is now a "100-year flood" as frequently as once every three years by the end of the 21st century.[157]

However, the increased risk of major flooding in the Columbia basin is expected to occur at the same time that the region *also* becomes more susceptible to summertime drought, due to reduced summer precipitation, a reduction in the availability of water from snowmelt, and higher temperatures. Indeed, the same study that projected a dramatic increase in the frequency of severe floods also projected that the Columbia basin could experience triple the number of drought days and lower total discharge from the Columbia over the course of the year under a scenario marked by dramatic increases in global warming pollution.[158]

Earlier snowmelt in the West may also contribute to increased wildfire risk. Large wildfire activity in the American West has increased significantly since the mid-1980s, with the greatest increases happening in northern Rockies forests. The increase in the number of large wildfires there has its roots in higher spring and summer temperatures (resulting either from natural variability or global warming) that have resulted in earlier snowmelt, leaving forests devoid of moisture for longer periods of the summer.[159]

Ecosystem Changes

America's ecosystems play an important role in mitigating the impact of extreme weather events. Global warming, however, could make ecosystems less resilient and increase the risk that extreme weather events will trigger disasters.

For example, global warming is expected to bring major changes to America's forests. Tree species are expected to move toward the north and upslope, while there are already signs of increasing destructive impacts from invasive species and insect pests, some of which may be linked to rising temperatures.[160]

Global warming-induced shifts in pest populations and invasive species – as well as shifts in forest species composition – may further alter fire risk. The invasion of non-native grassland species in arid portions of the West is expected to increase fire risk in these regions.[161]

Extreme Weather 2011: October Northeast Snowstorm

States affected: Massachusetts, New Hampshire, Connecticut, New Jersey (declared disasters)

The northeastern United States is no stranger to snow. Nor is it a stranger to big storms in October. But a large snowstorm in October is something new. In fact, such an event hadn't happened in the region in at least 150 years, until October 2011.

Two days before Halloween, a major storm dumped up to a foot of snow across a section of the Northeast stretching from Virginia to Maine. In New York City, the storm represented only the third measurable October snowfall since 1869 and by far the largest. Hartford, Connecticut, received more than a foot of snow, shattering the previous record for October snowfall of 1.7 inches.[162] Concord, New Hampshire, posted its second-greatest 24-hour snowfall total ever – for *any* day in *any* month. Weather historian Christopher C. Burt of the Weather Underground website suggested that snow totals from the storm approached, and perhaps even exceeded, those of an 1804 "Snow Hurricane," making the event the Northeast's snowiest October storm in at least two centuries.[163]

Photo: Seth Gardner-Gould, FEMA

A rare October snowstorm caused massive disruption to power supplies and transportation in much of the Northeast.

While the snowfall totals were nothing out of the ordinary for the Northeast, the timing of the storm was, coming at a time when many trees in the region were still in full leaf. Autumn leaves acted like cups for the heavy, wet snow, helping to bring down trees and limbs across the region, blocking roads and severing power lines. The most concentrated impacts were in southern New England, where more than three quarters of a million people in Connecticut and half a million in Massachusetts lost power during the storm – some of them for as long as 10 days.[164] New York City officials estimated that as many as 1,000 trees in Central Park may have been lost to the storm, 10 times as many as were lost during Hurricane Irene two months earlier.[165] A National Weather Service official, quoted by Britain's *The Guardian* newspaper, called the results of the storm in the region "absolute tree carnage."[166]

At least 27 people lost their lives in the storm.[167] As of January 2012, major disasters had been declared in 26 counties in four states housing nearly 12 million people.[168] In New Jersey, eight people died, including one elderly couple who died from carbon monoxide poisoning from a gas generator and another who died in a house fire sparked by a kerosene lamp. Both couples were in houses that had lost power.[169]

Communities in parts of the Northeast were forced to cancel Halloween observances due to dangerous conditions, while school systems depleted much of their year's allocation of snow days before fall had even reached its halfway point. In total, the storm was estimated to have caused more than $3 billion worth of damage.[170]

A massive October snowstorm would not appear to be connected to global warming. However, what was exceptional about the storm was not the cold but the convergence of cold with a moisture-packed storm of the type that scientists believe will be capable of holding and dropping more precipitation in a warming world. Weather Underground's Christopher Burt noted that no weather station in the Northeast broke a low temperature record on the day of the storm.[171]

Weather-Related Disasters Affect Nearly Every American

Each year, a series of high-profile weather disasters captures the attention of the media and the public. There was no shortage of such high-profile events in 2011, during which the nation experienced a record 14 individual billion-dollar weather disasters that collectively inflicted a minimum of $55 billion in total damage.[172] However, there were still other weather-related disasters that did not attract national headlines.

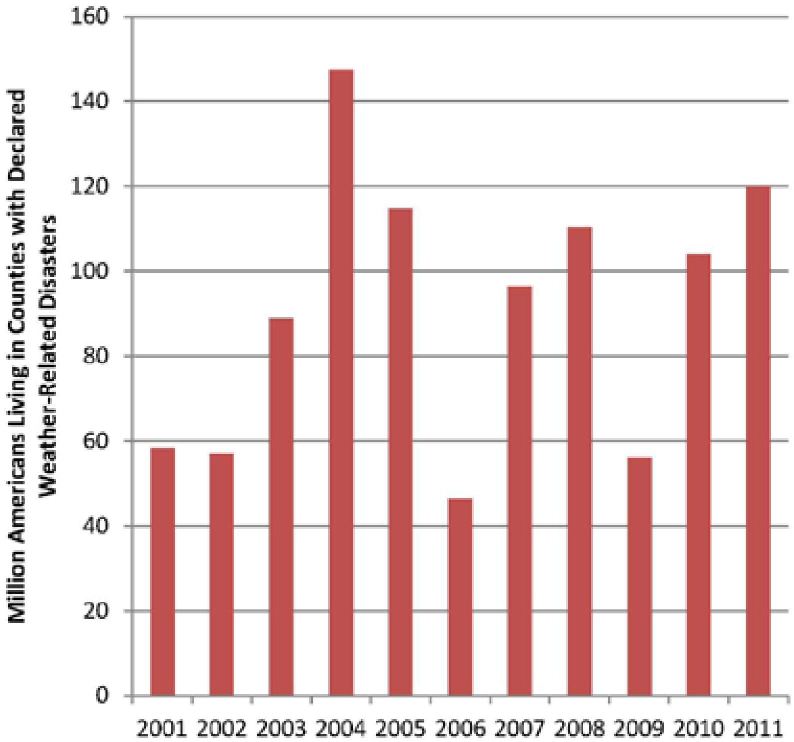
Weather-related disasters can strike anywhere in the United States. With global warming threatening to increase the severity and frequency of some extreme weather events – while simultaneously weakening the ability of our infrastructure and ecosystems to cope with those events – Americans need to understand the degree to which extreme weather puts our public safety and all of our communities at risk.

Weather-Related Disasters Are Common in the United States

Since the beginning of 2006, weather-related disasters have been declared in counties housing 242 million people in the United States – or four out of every five Americans.

Between 2001 and 2010, weather-related disasters struck counties housing an average of 88 million people – or more than one out of every four Americans – annually. In other words, in any given

Figure 3. Number of Americans Living in Counties with Declared Weather-Related Disasters, By Year



year, federal disaster assistance is required in counties housing about one quarter of all Americans.

The year 2011 saw the second-greatest number of Americans affected by weather-related disasters since 2001, with nearly 120 million Americans living in counties with declared weather-related disasters. Only 2004 – an extremely active year for landfalling hurricanes and tropical storms – saw more Americans affected by weather-related disasters.

Geographically, weather-related disasters affect every part of the United States. In 2011, weather-related disasters affected residents of 41 states and the District of Columbia. Since 2006, the only state to have not experienced a federally declared, weather-related disaster was South Carolina.

Many areas of the country have experienced more than one weather-related disaster since the beginning of 2006 – indeed, most Americans live in a county that has experienced two or more weather-related disasters. More than 15 million Americans live in counties that have averaged one or more weather-related disasters *per year* since the beginning of 2006.

From 2006-2011, the areas of the country most prone to multiple weather-related disasters were the Plains states, with weather-related disasters also common in the extreme Northwest and in New England. Ten U.S. counties – six in Oklahoma, two in Nebraska and one each in Missouri and South Dakota – experienced at least 10 declared weather-related disasters between 2006 and 2011.

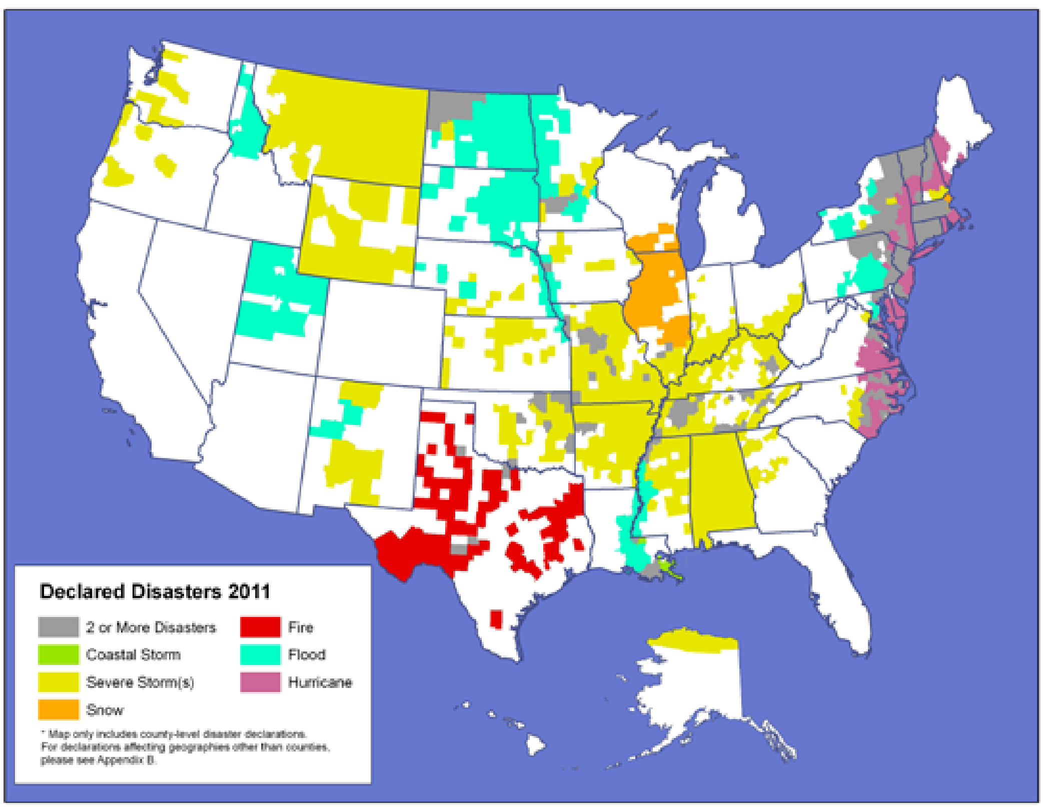
Eastern Oklahoma – home of several counties that have experienced multiple weather disasters – is indicative of the varied impacts of severe weather. In May 2011, eastern Oklahoma experienced an outbreak of tornadoes, just a month after torrential rains totaling more than 10 inches in some locations caused some rivers in the region – which had been previously experiencing a drought – to reach record crests.[181] In January 2010, Oklahoma was hit by an ice storm a little more than a month after a rare blizzard on Christmas Eve 2009 paralyzed travel in parts of the state.[182] Before that, the area suffered through severe storms and flooding in April 2008, an ice storm in December 2007, tornadoes and severe storms in June 2007, another ice storm in January 2007, and another tornado event in March 2006. This list does not include the extreme heat that affected the region during the summer of 2011, but which did not trigger a disaster declaration.

A detailed breakdown of the number of residents of each state living in counties with declared weather-related disasters can be found in Appendix A.

Severe Storms Are the Most Frequent Cause of Weather-Related Disasters

Severe storms – a broad category of weather events that includes many types of non-coastal storms – are the most common trigger of weather-related federal disaster declarations, with nearly two in three Americans living in areas that experienced a severe storm-related disaster declaration between 2006 and

Figure 4. Federally Declared Weather-Related Disasters in 2011



2011. Hurricanes, snowstorms, floods and fires round out the top five causes of disaster declarations. (See Table 2, next page. Note, however, that while severe weather events may bring several types of impacts – e.g., a severe storm may include tornadoes and cause a flood – only the primary event, as represented in FEMA's disaster declaration database, is included here.)

Figure 7 (page 38) shows the U.S. counties that have experienced presidentially declared weather-related disasters since the beginning of 2006 by type of disaster.

The relationship between global warming and weather-related disasters is complex. Some types of disasters – those in which intense rainfall or extreme heat are contributing factors – could reasonably be expected to become more

Figure 5. 2010 Population of Counties with Declared Weather-Related Disasters by Number of Disasters, 2006-2011

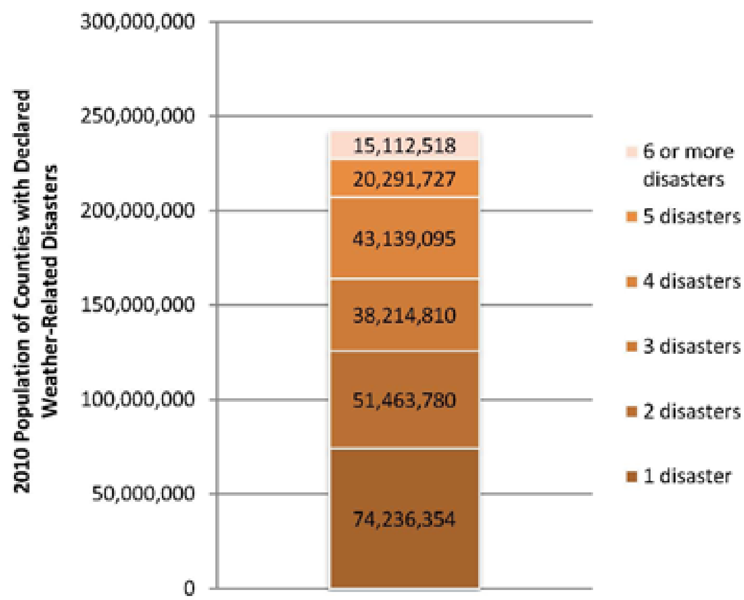


Figure 6. Number of Declared Weather-Related Disasters by County, 2006-2011

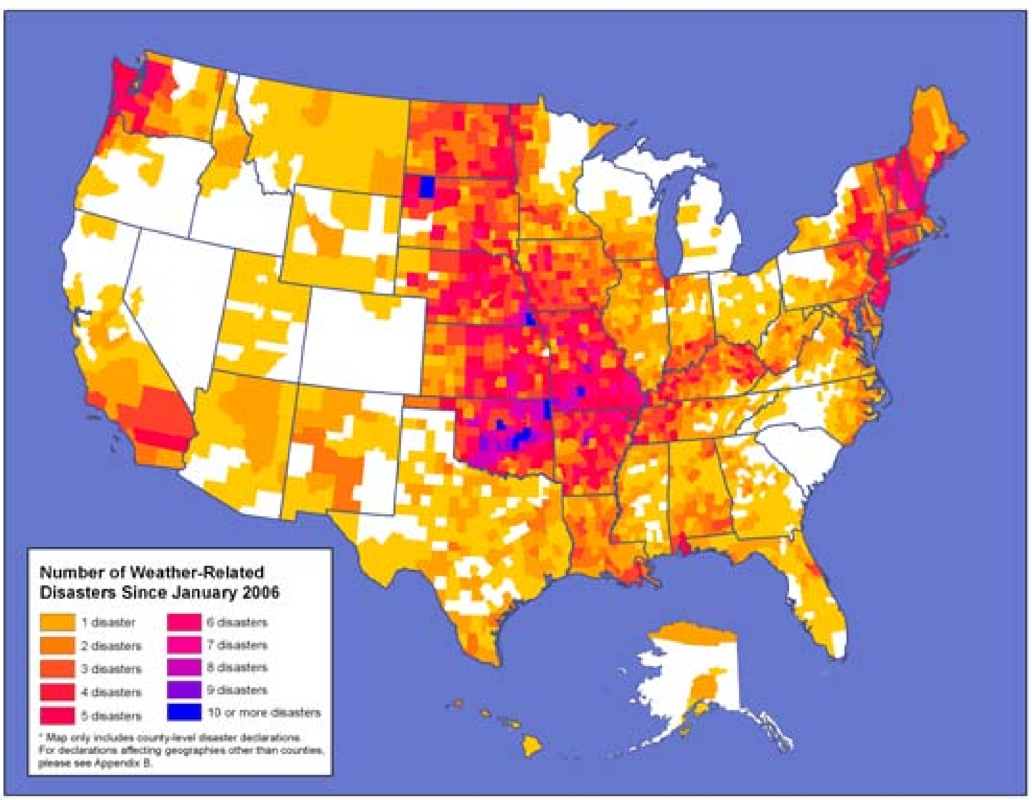


Table 2. Population (2010) of Counties by Type of Declared Weather-Related Disaster, 2006-2011

Incident Type	Population (2010) of Counties Affected
Severe Storm(s)	200,068,562
Hurricane	66,094,730
Snow	50,070,842
Flood	42,939,189
Fire	26,530,936
Freezing	22,531,557
Severe Ice Storm	18,906,600
Tornado	7,073,834
Coastal Storm	788,341

frequent and/or more severe in the years to come. Similarly, global warming may change underlying conditions – reducing the resiliency of ecosystems or increasing sea level along the nation's coasts, for example – in ways that increase the amount of damage caused by even routine events.

In other cases, the implications of global warming on weather-related disasters are less clear. There is little certainty about how global warming will affect tornadoes, hail, thunderstorms and other events that are major causes of weather-related disaster in the United States. Global warming may even make some types of weather-related disasters less likely.

However, the increasing evidence linking global warming to certain types of extreme weather events – underscored by the degree to which those events are already both a common and an extremely disruptive fact of life in the United States – suggests that the nation should take the steps needed now to prevent the worst impacts of global warming and to prepare for the changes that are inevitably coming down the road.

What about Drought?

Drought is a particularly devastating form of weather-related disaster, especially in its effects on farmers. However, presidentially declared severe disasters for drought are rare – none have been declared since 1965. Drought "emergencies" – another category of response, pertaining to ongoing situations – are also rare, with none having been declared since 1993.

There have been many declarations of natural disasters for drought, but those declarations are made through a different mechanism than the other disasters discussed in this report. A natural disaster declaration by the secretary of the U.S. Department of Agriculture (USDA) is necessary to unlock federal assistance for farmers who have lost crops due to drought. In 2011, for example, the USDA declared virtually the entire state of Texas a natural disaster area as a result of the state's exceptional drought.[184]

Because of these differences in the process for declaring disasters, drought-related events are largely missing from FEMA's disaster declaration database, with the exception of disasters declared as a result of wildfire, and are therefore absent from the tabulations in this section.

Photo: FEMA

Intense rains from Tropical Storm Lee caused record flooding along the Susquehanna River. Above, a floodwall protects a hospital from the floodwaters that inundated parts of Binghamton, NY.

Extreme Weather 2011: Tropical Storm Lee

States affected: Louisiana, Virginia, Maryland, New Jersey, Pennsylvania, New York (declared disasters)

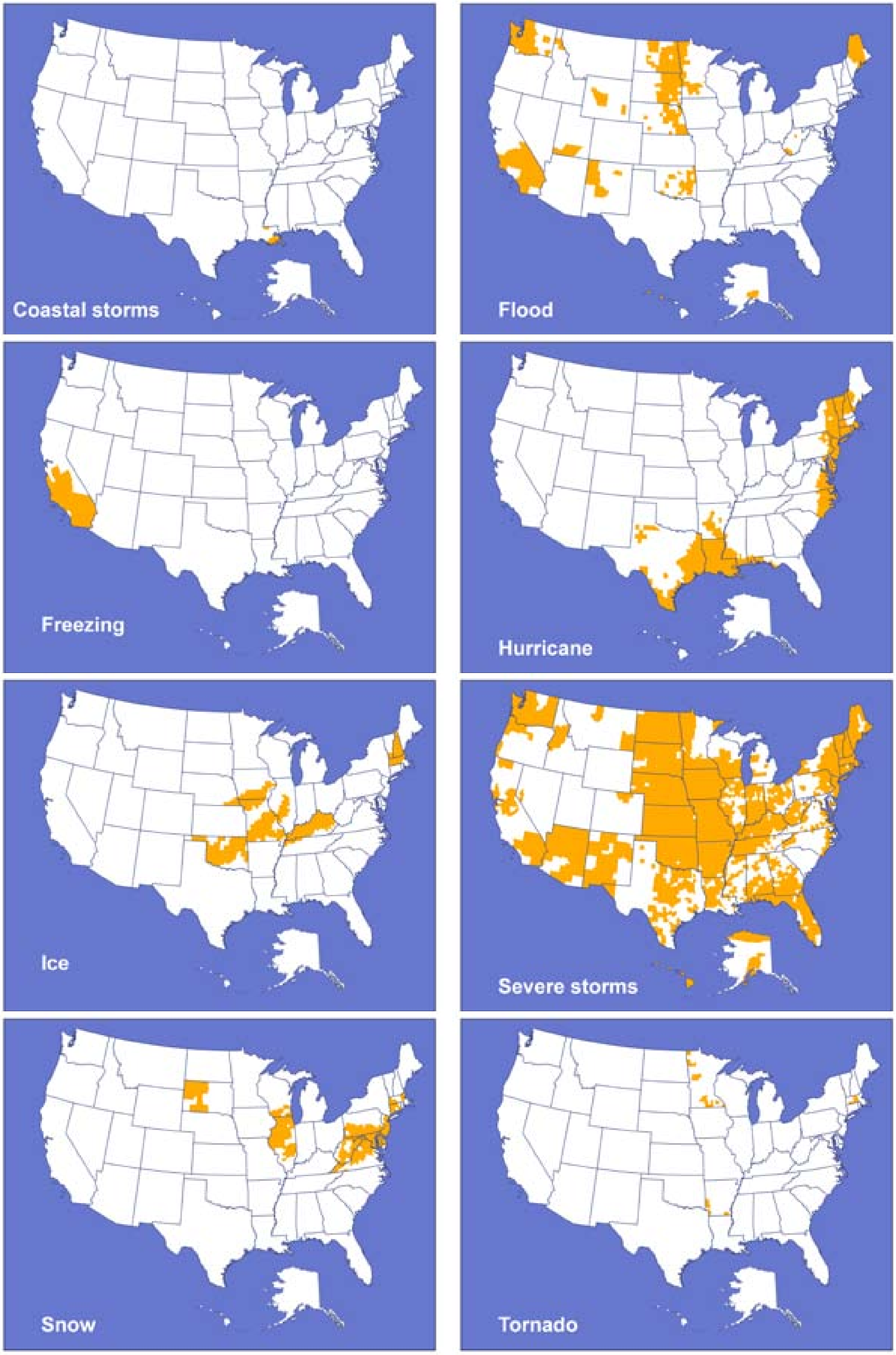
Just one week after Hurricane Irene struck the East Coast, a new tropical storm formed in the Gulf of Mexico. Unlike Irene, Lee never developed into a hurricane. Like the earlier storm, however, it delivered a tremendous amount of rainfall, causing catastrophic flooding in parts of Pennsylvania and New York state.

After drenching Louisiana and Mississippi, the remnants of Lee moved north, depositing heavy rains over the Susquehanna River valley and neighboring portions of Pennsylvania and New York. Binghamton, NY, reported its second "100-year" rainfall in two years, sending the Susquehanna River to its highest flood level in more than 150 years of record-keeping, and inundating the city's downtown for the second time in five years.[173]

Flooding from Tropical Storm Lee forced the evacuation of roughly 100,000 people in the Northeast and was believed to be responsible for at least 14 deaths.[174] Tropical Storm Lee and its remnants triggered major disaster declarations in 75 counties in six states that are home to more than 16 million people.[175] And the impact extended beyond humans – two bison at Zoo America in Hershey died amidst rising floodwaters, while more than 100 animals at a pet shop in Johnson City, NY, perished when store workers were unable to reach them during the flood. [176]

In Pennsylvania, flooding along the Susquehanna surpassed even that of the devastating flooding brought by Hurricane Agnes in 1972.[177] Numerous river and stream gauges in central Pennsylvania posted record or near-record flood levels.[178] Swatara Creek near Hershey set a new flood record, cresting 10 feet above the previous high water level and nearly 20 feet above flood stage.[179] Economic damages from the storm exceeded $1 billion.[180]

Figure 7 (a-h). Counties with Presidentially Declared, Weather-Related Disasters, 2006-11[183]



Conclusions and Recommendations

Weather-related disasters impose massive costs on the nation and threaten the health and survival both of people affected by those events and of treasured ecosystems. Recent scientific findings about the potential impacts of global warming on extreme weather patterns provide yet another reason for the United States and the world to take action against global warming.

Among the steps that can be taken to protect Americans from the threat of further global warming-induced extreme weather events are the following:

Federal, state and local governments should adopt and implement public policies designed to move the nation away from our dependence on fossil fuels while building momentum for future comprehensive action to curb global warming pollution. Specifically, federal, state and local governments should adopt:

- Aggressive energy efficiency standards for buildings, appliances, equipment and vehicles designed to get the most out of our current consumption of fossil fuels.
- Expanded renewable electricity standards and clean fuel standards to increase the production of clean, environmentally friendly energy in the United States.
- Increased investment in clean transportation options, such as public transportation, as well as research, development and deployment of new clean energy technologies.
- Strong steps to clean up existing sources of pollution, including strong regulations on the production of carbon dioxide and other pollutants by fossil fuel-fired power plants and the expansion and strengthening of carbon cap-and-trade programs such as the pioneering Regional Greenhouse Gas Initiative in the Northeast.

Environment America Research & Policy Center's 2011 report, *The Way Forward on Global Warming*, found that these and other policies at the local, state and federal level could reduce carbon dioxide emissions from fossil fuel use in the United States to as much as 34 percent below 2005 levels – even without adoption of comprehensive climate and energy legislation in the United States Congress.

Ultimately, however, federal and state governments should **adopt and implement limits on global warming pollution** capable of reducing emissions by at least 35 percent below 2005 levels by 2020 and by at least 85 percent by 2050. These emission reductions are broadly consistent with what science tells us is necessary to lessen the most costly and devastating consequences of global warming.

As the United States curbs emissions, we also need to **anticipate future changes in extreme weather that put the public at risk and take steps to prepare and protect our communities**. Government officials should explicitly factor the potential for global warming-induced changes in extreme weather patterns into the design of public infrastructure and revise policies that encourage construction in areas likely to be at risk of flooding in a warming climate. The nation should support the continued efforts of scientists to understand the implications of global warming and inform the public.

Methodology

Data on federal disaster declarations were obtained primarily from the Federal Emergency Management Agency's (FEMA) *Disaster Declarations Summary*, updated on December 5, 2011. This dataset contains information on disasters declared through November 8, 2011. In an effort to provide a complete picture of weather-related disasters in 2011, we supplemented the dataset by consulting FEMA's online disaster information, which can be found at **www.fema.gov/news/disaster_totals_annual.fema**. As a result, this report includes data on all disasters that began on or before December 31, 2011 and were declared prior to January 16, 2012. Due to delays in the issuance of disaster declarations, there may be additional disasters that began in 2011 that are not included in this report.

Disasters were classified by year based on the date on which the weather event precipitating the disaster began – not the date on which the disaster was formally declared. "Weather-related" disasters were assumed to include all disasters whose primary characteristic ("incident type" in the FEMA database) was listed as coastal storm, fire, flood, freezing, hurricane, severe ice storm, severe storm, snow or tornado. To streamline data processing and representation, only declarations for counties and county equivalents (such as parishes in Louisiana or boroughs in Alaska) are included in our totals. Declarations listed as being "statewide," for Indian reservations, for non-standard geographies, or for county-level jurisdictions that no longer exist were excluded from the totals in this report (though declarations for these geographies are listed separately in Appendix B.)

All county population totals for 2010, 2011 and 2006-2011 are based on 2010 county population counts from the 2010 U.S. Census. All data for previous individual years are based on population estimates for that year from the U.S. Census Bureau.

Appendices

Appendix A: Population of Counties with Declared Weather-Related Disasters by State and Year

(Note: Population totals include only county-level disaster declarations. For a list of disaster declarations for geographies other than counties, see Appendix B.)

State	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2006-2011	Pct. of state population affected, 2006-11
AK	0	251,346	390,054	7,363	14,172	133,413	0	106,897	101,725	0	9,430	266,824	38%
AL	2,016,069	2,794,718	3,472,560	4,512,190	3,338,801	0	1,107,003	585,344	2,587,568	231,151	4,779,736	4,779,736	100%
AR	834,184	469,880	839,767	808,956	0	198,699	0	2,781,148	2,460,103	2,440,363	2,440,363	2,915,918	100%
AZ	0	340,240	903,320	715,005	4,358,896	1,447,315	0	0	0	807,130	0	2,200,383	34%
CA	0	0	17,099,603	21,360,490	29,784,861	5,562,224	24,864,633	15,259,967	0	22,560,877	0	30,486,369	82%
CO	303,069	4,391,651	0	0	0	0	0	541,741	0	0	0	552,455	11%
CT	0	0	0	0	1,584,968	0	3,340,433	0	0	2,337,465	3,574,097	3,574,097	100%
DC	578,042	0	577,777	0	0	0	0	0	599,657	601,723	601,723	601,723	100%
DE	0	0	814,905	516,887	0	180,508	0	0	0	897,934	359,455	897,934	100%
FL	2,408,800	0	3,920,177	17,375,259	10,318,451	494,302	1,281,958	10,795,252	2,382,419	0	0	11,391,909	61%
GA	0	0	0	5,152,104	0	0	448,059	2,638,933	5,796,237	1,346,568	1,346,568	6,885,669	71%
HI	0	0	0	894,406	0	965,546	378,042	966,620	0	0	0	1,360,211	100%
IA	770,572	975,130	0	2,508,969	0	0	2,333,993	2,697,696	654,696	1,960,908	619,950	3,046,355	100%
ID	0	0	0	0	48,844	0	0	149,853	0	83,466	117,935	323,628	21%
IL	383,295	2,469,648	435,317	833,090	0	1,411,837	7,782,432	10,296,076	303,995	6,652,061	11,401,865	12,389,994	97%
IN	0	3,172,434	4,417,012	4,930,168	6,147,470	719,705	491,332	5,983,272	2,480,960	1,408,564	1,408,564	6,077,093	94%
KS	27,904	1,938,188	534,749	756,375	1,624,050	536,666	1,942,533	787,593	2,063,615	554,295	533,798	2,308,939	81%
KY	431,942	1,440,242	2,698,826	3,540,358	76,895	0	246,299	2,694,374	3,979,810	2,273,571	2,891,972	4,226,575	97%
LA	2,831,333	3,755,909	0	3,595,571	4,497,691	1,442,723	780,075	4,451,513	484,021	1,837,957	1,837,957	4,533,372	100%
MA	5,346,516	0	0	4,343,790	6,202,029	2,914,958	2,287,244	3,850,784	0	5,480,873	6,537,457	6,537,457	100%
MD	0	238,620	5,496,708	0	0	998,890	0	0	3,825,295	5,695,628	4,148,642	5,773,552	100%
ME	573,448	934,065	347,092	0	853,950	200,757	1,079,478	1,026,304	352,939	764,970	320,189	1,328,361	100%
MI	0	146,860	0	7,689,691	0	0	0	1,152,506	0	0	0	1,159,294	12%
MN	4,539,356	482,450	0	294,107	109,441	164,095	318,316	135,090	452,330	1,868,154	3,567,513	4,319,080	81%
MO	0	3,663,395	4,546,142	1,603,210	0	3,382,161	4,837,368	4,916,345	2,026,427	1,269,303	3,625,715	5,988,927	100%

Appendix A: Population of Counties with Declared Weather-Related Disasters by State and Year

(continued)

State	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2006-2011	Pct. of state population affected, 2006-11
MS	2,302,512	793,898	1,412,169	1,827,033	2,900,116	0	0	1,170,900	311,620	469,436	1,521,709	2,353,382	79%
MT	187,413	42,954	0	0	0	0	0	16,656	0	21,909	792,387	792,387	80%
NC	0	5,523,220	4,853,128	4,711,597	694,485	0	0	380,664	693,713	967,723	3,881,328	4,638,827	49%
ND	491,429	114,864	11,100	214,955	456,364	275,806	289,056	0	638,547	621,169	632,618	672,591	100%
NE	185,007	0	612,824	1,366,330	408,231	537,150	344,874	1,548,575	1,582,359	1,627,853	1,023,589	1,825,037	100%
NH	0	0	117,729	0	809,960	1,159,296	1,317,343	1,321,872	0	1,098,392	1,239,353	1,316,470	100%
NJ	0	0	0	1,707,254	3,665,777	752,867	6,981,744	0	2,419,475	8,533,937	8,791,894	8,791,894	100%
NM	0	0	0	679,708	0	776,389	54,092	84,254	0	251,496	364,055	1,024,352	50%
NV	0	0	0	55,797	2,300,558	0	0	52,813	0	0	0	51,980	2%
NY	19,088,978	0	3,254,952	19,297,933	3,124,758	4,219,594	9,654,506	1,074,033	4,146,116	11,736,483	16,769,524	18,056,084	93%
OH	1,409,145	4,269,613	6,864,342	11,464,593	0	2,780,878	494,966	5,566,793	0	1,803,671	1,803,671	9,499,850	82%
OK	1,830,048	2,647,542	1,800,144	0	3,532,769	67,966	3,476,989	1,174,793	3,420,907	2,680,384	1,896,052	3,751,351	100%
OR	0	616,225	2,655,759	0	1,376,280	447,989	931,130	2,242,245	0	612,960	612,960	2,637,272	69%
PA	1,738,275	0	1,420,270	12,388,368	1,884,397	5,232,806	0	0	0	8,031,927	8,239,599	11,308,289	89%
RI	0	0	0	0	0	0	81,305	0	0	1,052,567	1,052,567	1,052,567	100%
SC	0	976,280	0	3,533,186	1,153,719	0	0	0	0	0	0	0	0%
SD	213,327	0	0	220,390	243,575	43,843	191,395	217,117	184,585	584,180	330,520	705,016	87%
TN	1,214,524	1,962,331	5,230,201	710,130	0	1,250,388	0	1,798,680	1,736,270	3,756,455	4,819,694	5,845,403	92%
TX	6,000,103	10,501,212	938,180	0	22,801,920	723,981	13,848,695	11,077,609	0	2,041,234	3,855,681	21,053,094	84%
UT	0	0	0	0	331,416	0	0	0	0	150,412	2,200,169	2,350,581	85%
VA	292,930	654,116	7,095,102	1,535,729	0	2,427,156	0	0	4,881,261	3,328,454	4,661,500	7,221,388	90%
VT	0	133,355	167,313	358,771	0	0	377,579	379,203	0	228,766	625,741	625,741	100%
WA	0	0	4,295,958	0	0	4,968,040	3,453,229	6,148,022	4,978,827	2,199,882	2,199,882	6,644,989	99%
WI	1,364,774	885,687	0	4,747,745	0	0	1,475,463	3,867,622	0	1,471,640	2,249,089	4,305,553	76%
WV	981,056	465,532	1,707,680	1,258,059	160,015	0	460,859	357,791	729,224	1,187,565	0	1,717,607	93%
WY	0	0	0	0	37,061	0	0	0	0	48,790	290,724	290,724	52%
Total	**58,344,051**	**57,051,605**	**88,930,860**	**147,515,567**	**114,841,920**	**46,417,948**	**96,952,423**	**110,296,950**	**56,274,701**	**115,580,246**	**119,977,235**	**242,458,284**	**79%**

Appendix B: Disaster Declarations for Non-County Geographies

Major disasters are typically declared at the county level. In some cases, however, other geographies are used. These other geographies are most relevant in the cases of disasters declared in Alaska and for Indian reservations. These geographies may overlap with counties in which disasters were declared and are not included in the population figures elsewhere in this report.

Beginning Date of Disaster	Disaster Type	Description	Affected Area	State
3/30/2006	Severe Storm(s)	SEVERE STORMS, FLOODING, AND GROUND SATURATION	TURTLE MOUNTAIN INDIAN RESERVATION ND	ND
5/13/2006	Flood	SNOW MELT AND ICE JAM FLOODING	LOWER KUSKOKWIM REGIONAL EDUCATIONAL ATTENDANCE AREA AK	AK
5/13/2006	Flood	SNOW MELT AND ICE JAM FLOODING	LOWER YUKON REGIONAL EDUCATIONAL ATTENDANCE AREA AK	AK
5/13/2006	Flood	SNOW MELT AND ICE JAM FLOODING	YUKON KOYUKUK REGIONAL EDUCATIONAL ATTENDANCE AREA AK	AK
7/25/2006	Severe Storm(s)	SEVERE STORMS AND FLOODING	GILA RIVER INDIAN RESERVATION AZ	AZ
7/25/2006	Severe Storm(s)	SEVERE STORMS AND FLOODING	HOPI INDIAN RESERVATION AZ	AZ
7/25/2006	Severe Storm(s)	SEVERE STORMS AND FLOODING	NAVAJO NATION RESERVATION AZ	AZ
7/25/2006	Severe Storm(s)	SEVERE STORMS AND FLOODING	SAN CARLOS INDIAN RESERVATION AZ	AZ
7/25/2006	Severe Storm(s)	SEVERE STORMS AND FLOODING	TOHONO O'ODHAM RESERVATION AZ	AZ
7/26/2006	Severe Storm(s)	SEVERE STORMS AND FLOODING	NAVAJO NATION RESERVATION NM	NM
8/3/2006	Fire	FIRE	LOWER YUKON REGIONAL EDUCATIONAL ATTENDANCE AREA AK	AK
8/15/2006	Severe Storm(s)	SEVERE STORMS, FLOODING, LANDSLIDES, AND MUDSLIDES	CHUGACH REGIONAL EDUCATIONAL ATTENDANCE AREA AK	AK
10/8/2006	Severe Storm(s)	SEVERE STORMS, FLOODING, LANDSLIDES, AND MUDSLIDES	CHUGACH REGIONAL EDUCATIONAL ATTENDANCE AREA AK	AK
10/8/2006	Severe Storm(s)	SEVERE STORMS, FLOODING, LANDSLIDES, AND MUDSLIDES	COPPER RIVER REGIONAL EDUCATIONAL ATTENDANCE AREA AK	AK
12/14/2006	Severe Storm(s)	SEVERE WINTER STORM AND FLOODING	SILETZ INDIAN RESERVATION OR	OR
5/4/2007	Severe Storm(s)	SEVERE STORMS, TORNADOES, AND FLOODING	CROW CREEK INDIAN RESERVATION SD	SD
5/4/2007	Severe Storm(s)	SEVERE STORMS, TORNADOES, AND FLOODING	LAKE TRAVERSE INDIAN RESERVATION SD	SD
5/4/2007	Severe Storm(s)	SEVERE STORMS, TORNADOES, AND FLOODING	PINE RIDGE INDIAN RESERVATION SD	SD
12/1/2007	Severe Storm(s)	SEVERE STORMS, FLOODING, LANDSLIDES, AND MUDSLIDES	COOS, LOWER UMPQUA AND SIUSLAW INDIAN RESERVATION OR	OR
12/1/2007	Severe Storm(s)	SEVERE STORMS, FLOODING, LANDSLIDES, AND MUDSLIDES	GRAND RONDE INDIAN RESERVATION OR	OR
12/1/2007	Severe Storm(s)	SEVERE STORMS, FLOODING, LANDSLIDES, AND MUDSLIDES	SILETZ INDIAN RESERVATION OR	OR
6/2/2008	Severe Storm(s)	SEVERE STORMS AND FLOODING	CHEYENNE RIVER INDIAN RESERVATION SD	SD
6/2/2008	Severe Storm(s)	SEVERE STORMS AND FLOODING	CROW CREEK INDIAN RESERVATION SD	SD

Appendix B: Disaster Declarations for Non-County Geographies (continued)

Beginning Date of Disaster	Disaster Type	Description	Affected Area	State
6/2/2008	Severe Storm(s)	SEVERE STORMS AND FLOODING	LOWER BRULE INDIAN RESERVATION SD	SD
7/27/2008	Severe Storm(s)	SEVERE STORMS, FLOODING, LANDSLIDES, AND MUDSLIDES	YUKON KOYUKUK REGIONAL EDUCATIONAL ATTENDANCE AREA AK	AK
11/5/2008	Snow	SEVERE WINTER STORM AND RECORD AND NEAR RECORD SNOW	CHEYENNE RIVER INDIAN RESERVATION SD	SD
11/5/2008	Snow	SEVERE WINTER STORM AND RECORD AND NEAR RECORD SNOW	PINE RIDGE INDIAN RESERVATION SD	SD
11/5/2008	Snow	SEVERE WINTER STORM AND RECORD AND NEAR RECORD SNOW	ROSEBUD INDIAN RESERVATION SD	SD
11/5/2008	Snow	SEVERE WINTER STORM AND RECORD AND NEAR RECORD SNOW	STANDING ROCK INDIAN RESERVATION SD	SD
3/11/2009	Severe Storm(s)	SEVERE STORMS AND FLOODING	CHEYENNE RIVER INDIAN RESERVATION SD	SD
3/11/2009	Severe Storm(s)	SEVERE STORMS AND FLOODING	STANDING ROCK INDIAN RESERVATION SD	SD
3/13/2009	Severe Storm(s)	SEVERE STORMS AND FLOODING	LAKE TRAVERSE INDIAN RESERVATION ND	ND
3/13/2009	Severe Storm(s)	SEVERE STORMS AND FLOODING	SPIRIT LAKE RESERVATION ND	ND
3/13/2009	Severe Storm(s)	SEVERE STORMS AND FLOODING	STANDING ROCK INDIAN RESERVATION ND	ND
3/13/2009	Severe Storm(s)	SEVERE STORMS AND FLOODING	TURTLE MOUNTAIN INDIAN RESERVATION ND	ND
3/16/2009	Severe Storm(s)	SEVERE STORMS AND FLOODING	RED LAKE INDIAN RESERVATION MN	MN
3/16/2009	Severe Storm(s)	SEVERE STORMS AND FLOODING	WHITE EARTH INDIAN RESERVATION MN	MN
4/28/2009	Flood	FLOODING AND ICE JAMS	ALASKA GATEWAY REGIONAL EDUCATIONAL ATTENDANCE AREA AK	AK
4/28/2009	Flood	FLOODING AND ICE JAMS	KUSPUK REGIONAL EDUCATIONAL ATTENDANCE AREA AK	AK
4/28/2009	Flood	FLOODING AND ICE JAMS	LOWER KUSKOKWIM REGIONAL EDUCATIONAL ATTENDANCE AREA AK	AK
4/28/2009	Flood	FLOODING AND ICE JAMS	LOWER YUKON REGIONAL EDUCATIONAL ATTENDANCE AREA AK	AK
4/28/2009	Flood	FLOODING AND ICE JAMS	YUKON FLATS REGIONAL EDUCATIONAL ATTENDANCE AREA AK	AK
4/28/2009	Flood	FLOODING AND ICE JAMS	YUKON KOYUKUK REGIONAL EDUCATIONAL ATTENDANCE AREA AK	AK
4/28/2009	Flood	FLOODING AND ICE JAMS	YUPIIT REGIONAL EDUCATIONAL ATTENDANCE AREA AK	AK
12/18/2009	Severe Storm(s)	SEVERE WINTER STORMS AND FLOODING	EASTERN CHEROKEE INDIAN RESERVATION NC	NC

Appendix B: Disaster Declarations for Non-County Geographies (continued)

Beginning Date of Disaster	Disaster Type	Description	Affected Area	State
12/23/2009	Severe Storm(s)	SEVERE WINTER STORM AND SNOWSTORM	PINE RIDGE INDIAN RESERVATION SD	SD
12/23/2009	Severe Storm(s)	SEVERE WINTER STORM AND SNOWSTORM	ROSEBUD INDIAN RESERVATION SD	SD
1/18/2010	Severe Storm(s)	SEVERE WINTER STORMS AND FLOODING	GILA RIVER INDIAN RESERVATION AZ	AZ
1/18/2010	Severe Storm(s)	SEVERE WINTER STORMS AND FLOODING	HOPI INDIAN RESERVATION AZ	AZ
1/18/2010	Severe Storm(s)	SEVERE WINTER STORMS AND FLOODING	NAVAJO NATION RESERVATION AZ	AZ
1/18/2010	Severe Storm(s)	SEVERE WINTER STORMS AND FLOODING	SAN CARLOS INDIAN RESERVATION AZ	AZ
1/18/2010	Severe Storm(s)	SEVERE WINTER STORMS AND FLOODING	TOHONO O'ODHAM RESERVATION AZ	AZ
1/18/2010	Severe Storm(s)	SEVERE WINTER STORMS AND FLOODING	WHITE MOUNTAIN APACHE TRIBE AZ	AZ
1/20/2010	Severe Storm(s)	SEVERE WINTER STORM	CHEYENNE RIVER INDIAN RESERVATION SD	SD
1/20/2010	Severe Storm(s)	SEVERE WINTER STORM	LAKE TRAVERSE INDIAN RESERVATION SD	SD
1/20/2010	Severe Storm(s)	SEVERE WINTER STORM	STANDING ROCK INDIAN RESERVATION SD	SD
1/20/2010	Severe Storm(s)	SEVERE WINTER STORM	STANDING ROCK INDIAN RESERVATION ND	ND
2/26/2010	Flood	FLOODING	SPIRIT LAKE RESERVATION ND	ND
3/1/2010	Flood	FLOODING	PRAIRIE ISLAND COMMUNITY MN	MN
3/1/2010	Flood	FLOODING	UPPER SIOUX COMMUNITY MN	MN
4/1/2010	Severe Storm(s)	SEVERE WINTER STORM	STANDING ROCK INDIAN RESERVATION ND	ND
6/4/2010	Flood	FLOODING	WIND RIVER INDIAN RESERVATION WY	WY
6/15/2010	Severe Storm(s)	SEVERE STORMS AND FLOODING	ROCKY BOY'S INDIAN RESERVATION MT	MT
6/16/2010	Severe Storm(s)	SEVERE STORMS, TORNADOES, AND FLOODING	CHEYENNE RIVER INDIAN RESERVATION SD	SD
7/20/2010	Severe Storm(s)	SEVERE STORMS AND FLOODING	HOPI INDIAN RESERVATION AZ	AZ
7/25/2010	Flood	SEVERE STORMS AND FLOODING	NAVAJO NATION RESERVATION NM	NM
7/25/2010	Flood	SEVERE STORMS AND FLOODING	PUEBLO OF ACOMA NM	NM
9/22/2010	Severe Storm(s)	SEVERE STORMS AND FLOODING	FLANDREAU INDIAN RESERVATION SD	SD
10/3/2010	Severe Storm(s)	SEVERE STORMS AND FLOODING	HAVASUPAI INDIAN RESERVATION AZ	AZ
1/11/2011	Snow	SNOWSTORM	MASHANTUCKET PEQUOT INDIAN RESERVATION CT	CT
1/11/2011	Snow	SNOWSTORM	PAUCATUCK EASTERN PEQUOT INDIAN RESERVATION CT	CT
2/1/2011	Severe Storm(s)	SEVERE WINTER STORM AND EXTREME COLD TEMPERATURES	MESCALERO TRIBE NM	NM

Appendix B: Disaster Declarations for Non-County Geographies (continued)

Beginning Date of Disaster	Disaster Type	Description	Affected Area	State
2/1/2011	Severe Storm(s)	SEVERE WINTER STORM AND EXTREME COLD TEMPERATURES	PUEBLO OF ACOMA NM	NM
2/1/2011	Severe Storm(s)	SEVERE WINTER STORM AND EXTREME COLD TEMPERATURES	PUEBLO OF PICURIS NM	NM
2/1/2011	Severe Storm(s)	SEVERE WINTER STORM AND EXTREME COLD TEMPERATURES	PUEBLO OF POJOAQUE NM	NM
2/1/2011	Severe Storm(s)	SEVERE WINTER STORM AND EXTREME COLD TEMPERATURES	PUEBLO OF SAN FELIPE NM	NM
2/1/2011	Severe Storm(s)	SEVERE WINTER STORM AND EXTREME COLD TEMPERATURES	PUEBLO OF SANTA ANA NM	NM
2/1/2011	Severe Storm(s)	SEVERE WINTER STORM AND EXTREME COLD TEMPERATURES	PUEBLO OF SANTA CLAR NM	NM
2/1/2011	Severe Storm(s)	SEVERE WINTER STORM AND EXTREME COLD TEMPERATURES	PUEBLO OF TAOS NM	NM
2/1/2011	Severe Storm(s)	SEVERE WINTER STORM AND EXTREME COLD TEMPERATURES	SAN FELIPE PUEBLO NM	NM
2/14/2011	Flood	FLOODING	FORT BERTHOLD INDIAN RESERVATION ND	ND
2/14/2011	Flood	FLOODING	SPIRIT LAKE RESERVATION ND	ND
2/14/2011	Flood	FLOODING	STANDING ROCK INDIAN RESERVATION ND	ND
2/14/2011	Flood	FLOODING	TURTLE MOUNTAIN INDIAN RESERVATION ND	ND
3/16/2011	Flood	SEVERE STORMS AND FLOODING	RED LAKE INDIAN RESERVATION MN	MN
3/31/2011	Flood	FLOODING, LANDSLIDES, AND MUDSLIDES	NEZ PERCE INDIAN RESERVATION ID	ID
4/4/2011	Severe Storm(s)	SEVERE STORMS AND FLOODING	BLACKFEET INDIAN RESERVATION MT	MT
4/4/2011	Severe Storm(s)	SEVERE STORMS AND FLOODING	CROW INDIAN RESERVATION MT	MT
4/4/2011	Severe Storm(s)	SEVERE STORMS AND FLOODING	FORT BELKNAP INDIAN RESERVATION MT	MT
4/4/2011	Severe Storm(s)	SEVERE STORMS AND FLOODING	FORT PECK INDIAN RESERVATION MT	MT
4/4/2011	Severe Storm(s)	SEVERE STORMS AND FLOODING	NORTHERN CHEYENNE INDIAN RESERVATION MT	MT
4/4/2011	Severe Storm(s)	SEVERE STORMS AND FLOODING	ROCKY BOY'S INDIAN RESERVATION MT	MT
4/18/2011	Flood	FLOODING	UINTAH AND OURAY INDIAN RESERVATION UT	UT
5/8/2011	Flood	ICE JAM AND FLOODING	CROOKED CREEK (ANV/ANVSA) AK	AK
5/8/2011	Flood	ICE JAM AND FLOODING	KUSPUK REGIONAL EDUCATIONAL ATTENDANCE AREA AK	AK
5/8/2011	Flood	ICE JAM AND FLOODING	RED DEVIL (ANV/ANVSA) AK	AK

Appendix B: Disaster Declarations for Non-County Geographies (continued)

Beginning Date of Disaster	Disaster Type	Description	Affected Area	State
5/18/2011	Severe Storm(s)	SEVERE STORMS, FLOODING, AND LANDSLIDES	WIND RIVER INDIAN RESERVATION WY	WY
7/1/2011	Severe Storm(s)	SEVERE STORMS, FLOODING, AND TORNADOES	MILLE LACS INDIAN RESERVATION MN	MN
8/19/2011	Flood	FLOODING	ACOMA PUEBLO INDIAN RESERVATION NM	NM
8/19/2011	Flood	FLOODING	COCHITI PUEBLO INDIAN RESERVATION NM	NM
8/19/2011	Flood	FLOODING	SANTA CLARA PUEBLO INDIAN RESERVATION NM	NM
8/27/2011	Hurricane	TROPICAL STORM IRENE	STATEWIDE RI	RI
11/8/2011	Severe Storm(s)	SEVERE WINTER STORMS AND FLOODING	BERING STRAIT REGIONAL EDUCATIONAL ATTENDANCE AREA AK	AK
11/8/2011	Severe Storm(s)	SEVERE WINTER STORMS AND FLOODING	LOWER KUSKOKWIM REGIONAL EDUCATIONAL ATTENDANCE AREA AK	AK
11/8/2011	Severe Storm(s)	SEVERE WINTER STORMS AND FLOODING	LOWER YUKON REGIONAL EDUCATIONAL ATTENDANCE AREA AK	AK
11/8/2011	Severe Storm(s)	SEVERE WINTER STORMS AND FLOODING	SOUTHWEST REGIONAL EDUCATIONAL ATTENDANCE AREA AK	AK

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