Why the Emergency Management Community Should be Concerned about Climate Change

A discussion of the impact of climate change on selected natural hazards

CNA ANALYSIS & SOLUTIONS

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This document was prepared by CNA under a grant from the Rockefeller Foundation. This document represents the best opinion of CNA at the time of the issue. It does not necessarily represent the opinion of the Rockefeller Foundation.

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Executive summary

Increases in the concentrations of atmospheric greenhouse gases from activities such as burning fossil fuels and deforestation have caused a measurable increase in global temperatures. As greenhouse gas concentrations continue to increase, further changes in the Earth's climate are expected. These changes may impact the location, frequency, and occurrence of natural hazards such as tropical cyclones, wildfires, floods, and winter storms. Thus, the historical data that are typically the basis of hazard identification and risk assessment may not accurately forecast future events. Consequently, we need to begin to evaluate and better understand how climate change could affect the identification and selection of disaster mitigation strategies, the types of preparedness activities that jurisdictions undertake, the execution of response operations, and the implementation of long-term recovery strategies.

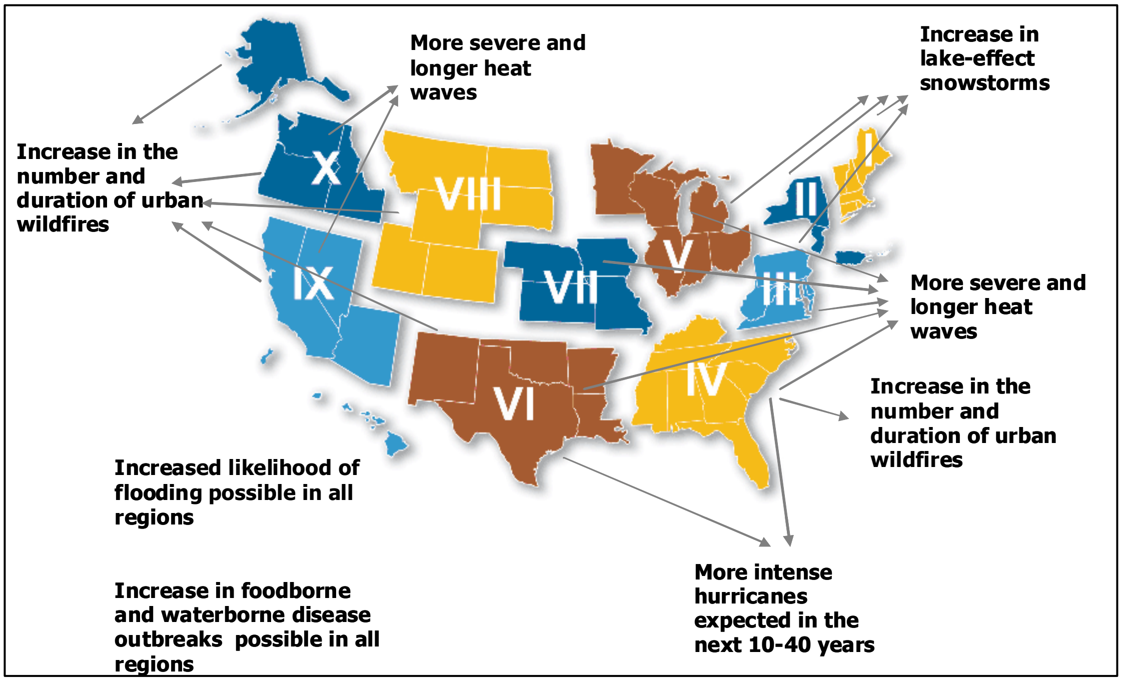
This report is one of several reports from CNA examining the impact of climate change on U.S. policy. This particular report focuses on the impact of climate change on comprehensive emergency management and preparedness policy. It seeks to outline key climate change issues for consideration from an emergency management perspective and begin a conversation on potential implications for the near-, medium-, and long-terms. It lays the foundation for future dialogue among emergency management practitioners from all levels of government to explore policy solutions in greater depth. The scientific foundation for much of the discussion in this report comes from the recently published report from the U.S. Global Change Research Program—*Global Climate Change Impacts in the United States*.

Impact of climate change on hazards

We identified several natural hazards that are both of significant interest to the emergency management community and are expected to be impacted by climate change, including tropical cyclones[1], floods, wildfires, winter storms, heat waves, and foodborne and waterborne disease outbreaks. Figure 1 summarizes the predicted impacts of climate change on hazards by region in the United States. The climate change literature indicates that all regions of the U.S. may be susceptible to an increase in frequency and/or severity of flooding and foodborne and waterborne disease outbreaks. Other climate-induced changes are predicted only in certain regions. We used the familiar Federal Emergency Management Agency (FEMA) regions to depict the impact of climate change. However, there are several hazards that may impact different segments of a FEMA region differently, or where an increased likelihood of a hazard may span multiple FEMA regions.

1. We use the term "tropical cyclones" here to include tropical storms, hurricanes, and typhoons.

Figure 1. Predicted impacts of climate change across the U.S.



POLICY IMPLICATIONS

Analysis of these hazard shifts will allow regions to incorporate emerging challenges into planning cycles and build response capabilities accordingly. This is further an opportunity to utilize the already established risk analysis process in the emergency management community to identify disaster mitigation and preparedness efforts to arm communities against these shifting hazards. A summary of key considerations is included here. A more detailed discussion to help policy-makers begin a dialogue on potential courses of action is included in the main body of this report.

DISASTER MITIGATION

- Adapt current disaster mitigation strategies to the anticipated short, medium-, and long-term impacts of climate change.
- Engage proactively with regional, State, and local climate research groups for data to support more accurate forecasts for the future occurrence of hazards affected by climate change.
- Coordinate with regional, State, and local climate change adaption planning groups to support the Hazard Identification and Risk Assessment (HIRA) process and develop regional disaster mitigation strategies.

PREPAREDNESS

- Review and update preparedness activities to account for changing risk profiles and their consequences.
- Encourage the inclusion of the emergency management community in regional, State, and local climate change adaptation planning processes and strategies.

- Consider and plan for the impacts on vulnerable populations.
- Incorporate information on the effects of climate change into existing community preparedness campaigns.

Response

- Develop models to estimate the financial impact of larger and more frequent response operations on local budgets.
- Anticipate command and control challenges, and develop new strategies to manage more frequent and complex disasters.

Recovery

- Increase the efficiency of the recovery process to deal with the aftermath of more frequent and/or more severe disasters.
- Consider developing rigorous criteria to help policy makers with post-disaster rebuilding decisions.
- Incentivize self-sufficiency and rapid essential service restoration in the private sector.

INTRODUCTION AND TASKING

This report is one of several from CNA examining the impact of climate change on U.S. policy. This particular report focuses on the impact of climate change on comprehensive emergency management and preparedness policy. The purpose of this report is to:

- Outline key climate change issues for the emergency management community at all levels of government.
- Begin a conversation on potential implications from near, medium, and long-term perspectives.

The scientific foundation for much of the discussion in this report comes from the recently published report from the U.S. Global Change Research Program—*Global Climate Change Impacts in the United States*.

In this report, we explore the challenges that local, State, and Federal emergency management personnel face in adapting to climate-induced changes to the risk profile of their community and the associated changes in disaster response and recovery requirements. We discuss the impact of these changes on the phases of emergency management and begin to frame courses of action that U.S. leaders should consider in order to plan for, build resilience for, respond to, and recover from domestic climate-related hazards. This report lays the foundation for future dialogue among emergency management practitioners from all levels of government to explore policy solutions in greater depth.

COMPREHENSIVE EMERGENCY MANAGEMENT: A PRIMER

Comprehensive emergency management is an integrated approach for anticipating, planning for, responding to, and recovering from all types of emergencies in order to minimize loss of life and property. Comprehensive emergency management includes four distinct but related phases:

- Disaster mitigation: the identification of potential hazards in a region followed by an assessment of the probability of their occurring and the likely impacts. Actions are then taken to lessen the impact of the identified hazards.
- Preparedness: a cycle of preparatory actions taken before an event happens that includes developing emergency plans, training personnel, testing those plans through exercises, updating plans based on lessons learned, and engaging with the community on how to prepare for potential emergencies.
- Response: active crisis management during an event.
- Recovery: the coordination of long-term community support to restore functions in a region and improve services after a disaster. This may include infrastructure, public health services or any provision of services the local government may normally supply [1].

Comprehensive emergency management establishes a logical and standardized framework for local, State, tribal, and Federal authorities to use in thinking about how to manage activities before, during, and after an incident takes place. All four phases of comprehensive emergency management are relevant to the climate change discussion. Therefore, each phase is discussed in greater depth below.

Disaster Mitigation

Disaster mitigation is continuous and sustained action to reduce or eliminate risks to people and property from all hazards. At its core, disaster mitigation is predicated on an understanding of the risks a given jurisdiction faces. A key element of disaster mitigation is the Hazard Identification and Risk Assessment (HIRA) process, in which jurisdictions identify the range of potential hazards that could impact a jurisdiction and then evaluate the risks to persons, public and private property, and structures. Risk is defined as the potential for an unwanted outcome resulting from an incident, event, or occurrence, as determined by its likelihood and the associated consequences [2]. The risk assessment process focuses on understanding the probability of a hazard occurring, the vulnerability or level of exposure of people and property in a jurisdiction to that hazard, and the potential consequences that the hazard may have in terms of human or economic loss, service disruption, or overall continuity of operations and public confidence. Particularly in the case of natural hazards, the HIRA process leverages historical and scientific data to better understand both the probability of hazards occurring and their potential impacts.

Ultimately, findings from the HIRA inform the broader decision-making processes inherent in disaster mitigation and preparedness activities. Knowing what hazards are more or less likely and the potential impacts they could bring allows planners to design and implement long-term strategies to control or eliminate risks to people and property in the community.

Disaster mitigation strategies are intended to reduce the impact of a disaster when one occurs or to avoid the impacts of one altogether. Disaster mitigation measures can be structural or non-structural. Structural measures use technological solutions, like flood levees and seawalls, to control the effects of a hazard. Non-structural disaster mitigation measures include land-use planning, design and construction codes, and financial and insurance incentives. Together, these tools offer a set of options that communities can use to strengthen their resilience to the range of hazards most relevant to them [1]. Community-based efforts that draw in local governments, non-governmental organizations, and the local business community are emphasized by Federal government guidance and grants.

Preparedness

Preparedness is defined as the continuous cycle of planning, organizing, training, equipping, exercising, evaluating, and taking corrective action in an effort to ensure effective coordination during incident response [3]. The preparedness mission cuts across virtually all other missions and activities, and encompasses all government partners at the local, State, and Federal levels. Preparing before an event occurs—for example, by developing operational plans and training and exercising with regional partners—positions jurisdictions to respond and recover more effectively when emergencies actually transpire. In essence, preparedness is a cross-cutting, enabling function that increases the effectiveness of the other phases of emergency management.

Preparedness activities help personnel who would be involved in incident response understand ahead of time what their roles and responsibilities will be and practice these functions in a safe and controlled environment. Clarity of roles and responsibilities for government and non-government entities in an emergency is critically important not only for disaster response personnel, but also for individuals acting in policy, coordination, or support roles. This is especially important for large disasters that involve multiple jurisdictions and levels of government.

Response

The response phase is the suite of actions taken immediately following an incident, including, but not limited to, treating injured persons, securing incident scenes, suppressing fires, conducting search and rescue operations, and assessing damages and structural integrity at affected facilities. Response is where the plans and procedures developed through the preparedness phase are actually implemented [4].

As the *National Response Framework* notes, local emergency management, police, fire, emergency medical services, public health and medical providers, public works, environmental response professionals, and others in the community are often the first to respond. Local emergency managers are critical partners in building the foundation for effective disaster response. They organize and integrate capabilities and resources with neighboring jurisdictions, State and Federal agencies, non-governmental organizations, and the private sector [5]. As incident scale expands, so does the level of involvement and required support from additional partners. For example, State personnel coordinate with other agencies to provide resources from within the State as well as from other States through mutual aid. When an incident occurs that exceeds or is anticipated to exceed local or State resources, the Federal government may provide resources and capabilities to support the State response. Thus, the larger and more complex the disaster, the larger the universe of government and non-government entities involved in the response.

Recovery

Recovery is the longer term process of returning a community to "normal" following an incident. Depending on the scale of the event, this phase can commence in the hours and days following the incident and continue for years afterward. Although emergency managers are involved in long-term recovery operations, the range of participants in recovery decision-making and program implementation stretches far beyond emergency management to include other government agencies (e.g.. housing, building code), private sector businesses, and members of the community [4].

Recovery and disaster mitigation activities are integrally related. Decisions made in the recovery phase about rebuilding housing, restoring businesses, and repairing infrastructure must balance the need to restore core functions in a community as efficiently as possible with the need to reduce the community's vulnerability to similar incidents in the future.

Why should emergency managers be concerned about climate change?

Climate change will likely impact all four phases of emergency management on some level. We must begin to evaluate and better understand how climate change could affect the identification and selection of disaster mitigation strategies, the types of preparedness activities that jurisdictions undertake, the execution of response operations, and the implementation of long-term recovery strategies.

Key to all of this is the impact that climate change may have on the HIRA process. For natural hazards, hazard identification and risk assessment is largely based on historical occurrence. However, research indicates that climate change is affecting future patterns of natural hazards. This will need to be taken into consideration when using historical data to model future events, thereby impacting how we approach disaster mitigation and the overall preparedness strategy.

Organization of this report

The first section following this introduction identifies those hazards that may be affected by climate change and then summarizes the potential effects based on a review of current climate change literature. The next section discusses the potential implications of those changes within the context of the four phases of emergency management. That section concludes with an outline of several high-level policy considerations for further evaluation by emergency management subject matter experts and practitioners. The appendix provides a more detailed discussion of climate change affects on the identified hazards.

THE IMPACT OF CLIMATE CHANGE ON HAZARDS

The first question we asked ourselves when considering the effect of climate change on comprehensive emergency management was "What are the hazards that could be affected by climate change?" Once we identified those hazards, we then sought to understand the potential effects of climate change on each hazard.

WHAT ARE THE HAZARDS THAT COULD BE AFFECTED BY CLIMATE CHANGE?

To answer this question, we first examined those hazards typically included in the HIRA process [6]. We then identified those natural hazards that would be affected by changes in the weather. Finally, we cross-referenced that list with the climate change literature to identify those natural hazards that are expected to be impacted by climate change. These include tropical cyclones, wildfires, floods, winter storms, and heat waves.[2,3] Additionally, we included food and waterborne diseases since they are considered plausible outcomes from climate change, which could result in a public health crisis requiring emergency management support.

2. There are several natural hazards that one would expect to be affected by climate change, including tornados, hail and ice storms, and landslides. In the case of tornados and hail and ice storms, it is unknown how and whether climate change will impact their frequency and/or severity [7]. Landslides can be an outcome of flooding, but are not directly discussed in the climate change literature.

3. Droughts and sea level rise, while likely results of climate change, are outside the scope of this report.

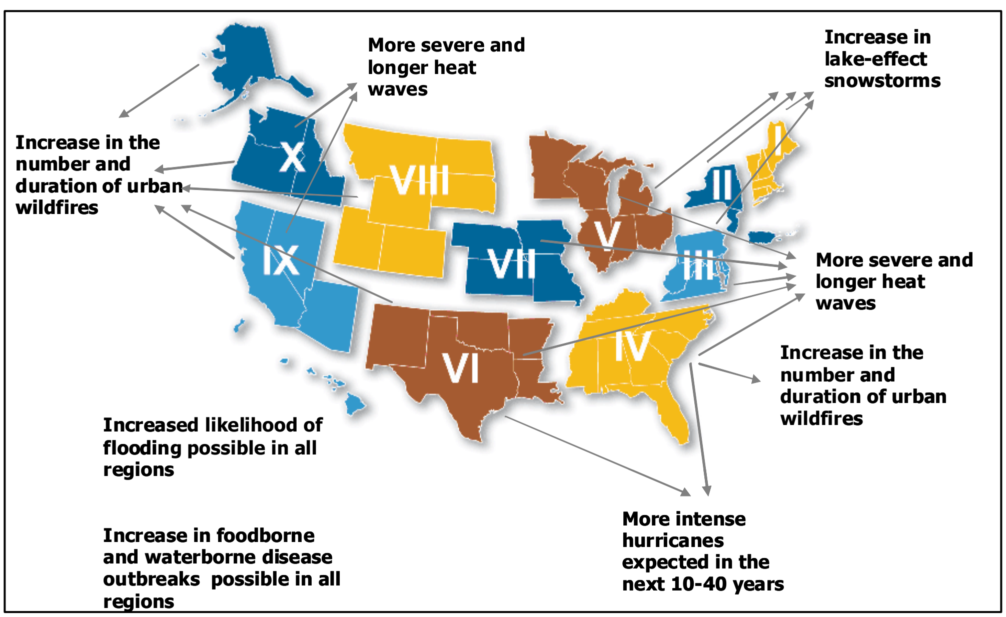
WHAT ARE THE EFFECTS THAT CLIMATE CHANGE IS PREDICTED TO HAVE WITH RESPECT TO THESE HAZARDS?

For each of these hazards, we then investigated the projected impact of climate change and the associated effects across the U.S. This information allowed us to draw some conclusions about how a change in the incidence and/or severity of a particular hazard could impact the emergency management community. It also allowed us to develop recommendations for how the emergency management community should be planning for those hazards affected by climate change.

Figure 2 summarizes the predicted impacts of climate change on hazards by region in the United States. We chose to use the existing FEMA regions to depict the impact of climate change on hazards by region since those regions are most familiar to the emergency management community. The climate change literature indicates that all regions of the U.S. may be susceptible to an increase in frequency and/or severity of flooding and foodborne and waterborne disease outbreaks. Some climate-induced changes are predicted to span multiple FEMA regions. For example, the projected increase in the frequency and/or severity of wildfires spans FEMA regions IV, VI, VIII, and X [8]. Other changes may only impact part of a FEMA region. For example, in FEMA Region VIII, the predicted increase in wildfire frequency and/or severity is more applicable for Utah and Colorado, than for the Dakotas.

Next, we summarize the projected effect of climate change on each of the hazards. A more detailed analysis of each hazard is provided in the appendix.

Figure 2. Predicted impacts of climate change across the U.S.



Tropical cyclones

For this report, we identified the tropical cyclones that threatened the U.S. mainland and territories over the last 10 years. We include strikes as well as landfalls because many tropical storms and hurricanes that do not make actual landfall nonetheless elicit a response from local, State, and Federal emergency management agencies. Historically, FEMA regions II, IV, and VI have been most susceptible to tropical cyclones.[4] According to the climate change literature, States along the Gulf and Southeast coasts, as well as islands in the Caribbean are projected to be most affected by climate-induced changes in hurricane activity in the future [7,8]. While these regions are accustomed to tropical storms and hurricanes, increases in storm intensity and/or frequency will further test community defense systems such as levies and other barriers, as well as processes for evacuation and sheltering.

Urban wildfires

Given that we are interested in the impact of hazards on emergency management activities, we narrowed our focus of wildfires to include only those fires that occurred at the wildland urban interface – the space where wildlands (and fires, when they occur) intersect communities [9]. In this paper, we refer to these as "urban wildfires."

Historically, FEMA regions IV, VI, VIII, and IX have been most susceptible to urban wildfires. According to the climate change literature, wildfires could increase in the western and southwetern United States [8,10,11,12]. In addition, the climate change literature suggests that temperature could increase in the southeast region of the U.S., which is a strong indicator for an increase in wildfires [8]. While these regions are accustomed to wildfires, increases in severity and/or frequency could further strain local emergency services and increase recovery costs if more people move into wildfire-prone areas.

Interestingly, the climate change literature also suggests that wildfire activity in the Pacific Northwest could increase [8]. While this region has seen some urban wildfires, they have been less frequent than in the southwest region. Therefore, this could become an emerging threat for the region, especially if the population density within the wildlife urban interface increases. A similar threat is also emerging for urban centers in Alaska, where large wildfires are already common [8].

Floods

We used the NOAA National Climate Data Center's classification for floods where flash, river, coastal, urban, and small stream floods are reported as "events," each of which impacts one or more counties, to identify the number of floods to impact the U.S. over the last 10 years.[5] For this study, we further narrowed the definition to those events that resulted in at least $1 million in property damage. In this report, we refer to these flood events as "large flood events."

Although there have been a substantial number of large flood events across the U.S., FEMA Regions II, III, IV, and V have been most affected by large flood events over the last 10 years. The enhanced hydrological cycle resulting

4. We include FEMA Region II in this list since Region II is responsible for U.S. territories in the Carribbean, such as Puerto Rico and the U.S. Virgin Islands, which are also susceptible to tropical cyclones.

5. We did not consider flooding as a result of global sea level rise, because that was outside the scope of this report.

from a warmer atmosphere is expected to yield more heavy precipitation events, but it is difficult to predict which areas across the U.S. will see an increase in precipitation and associated flooding events [8]. Therefore emergency management agencies across the U.S. need to be aware of the possibility of an increased likelihood of flooding in their area. Those regions more accustomed to large flooding are likely better equipped to handle an increase in frequency and/or severity of large flood events. Other regions, which are less accustomed to responding to these events, should begin to consider flooding in their disaster mitigation and preparedness strategies.

WINTER STORMS

We used the NOAA National Climate Data Center's classification for winter storms, where snow and ice storms are reported as "events," each of which impacts one or more counties, to identify the number of winter storms to impact the U.S. over the last 10 years. We further narrowed the definition to those events that resulted in at least $1 million in property damage. In this report, we refer to these flood events as "severe winter storms."

Historically, FEMA Regions I, II, III, and V account for more than half of all severe winter storms. One factor on that sets these regions apart from others in the U.S. is lake-effect snowfall. Lake-effect snowfalls are produced when cold air flows across large bodies of warmer water. According to climate change literature, these regions could experience warmer temperatures in the winter, which would result in warmer water temperatures on the Great Lakes and other large bodies of water. This in turn could increase the likelihood of more frequent and more severe lake-effect snowfalls [8]. Additional lake-effect snowstorms would further impact local and State emergency management agencies in those regions and could result in more significant economic and critical infrastructure strains on communities.

HEAT WAVES

There is no universally accepted definition of a heat wave in climate change literature. We chose a qualitative approach and determined that a heat wave occurs when there are a minimum of three consecutive excessive heat reports generated from NWS stations for the same location. FEMA Regions III, IV, V, VI, VII, and IX have experienced the most heat waves over the last 10 years. According to climate change literature, these regions are most likely to see an increase in heat wave severity [8,13]. While these regions may be more accustomed to heat waves, more severe and/or frequent heat waves will further tax local emergency management, public health, and social services.

Climate change literature also suggests that that the Pacific Northwest, which has not been as susceptible to heat waves historically, could also experience an increase in the number, duration, and intensity of heat waves in the future.

FOODBORNE AND WATERBORNE DISEASES

There are tens of thousands of reports of foodborne and waterborne diseases each year across the U.S. The climate change literature suggests that the number of cases could increase in the future. This is based on research that indicates that the incidence of foodborne and waterborne diseases is directly correlated to an increase in precipitation and temperature [8,14,15]. It is difficult to predict which areas across the U.S. will see an increase in temperature and precipitation. Therefore, emergency management and public health agencies across the U.S. need to be aware of the possibility of an increased likelihood of foodborne and waterborne disease outbreaks in their area.

IMPLICATIONS FOR THE EMERGENCY MANAGEMENT COMMUNITY

Climate-induced changes in the historical patterns of natural hazards will affect the HIRA process and disaster mitigation, preparedness, response, and recovery activities that it informs. Although the exact impact of climate change on weather patterns is not quantifiable, our literature review revealed two broad trends: an increase in frequency and an increase in severity of selected natural hazards.

Some disasters will likely happen with greater frequency in places where they already occur, placing people and property in those areas at a greater risk. Other areas may see more of certain disasters due to changes in the seasonality of that disaster (e.g., longer hurricane seasons). Still other disasters may occur in areas that have not historically experienced them on a regular basis, creating new risk where it has not previously existed. Depending on the area, this could result in "compound disasters," where one disaster triggers another. Finally, existing hazards may become more severe, leading to more damaging outcomes and potentially requiring significant external support (e.g., from Federal, State, or other sources) where previously none was needed. Overall, these two trends of increased disaster frequency and severity lead to a decrease in the ability of the current HIRA models to produce accurate hazard predictions.

The following section explores how these effects are relevant to the four phases of comprehensive emergency management and provides potential courses of action for the emergency management community to consider and to join the dialogue on climate change adaption strategies.

DISASTER MITIGATION

Climate change will affect the HIRA process and the disaster mitigation strategies selected to reduce the consequences of a disaster once it occurs. Important for HIRA, the historical models for hazard predictability may no longer be accurate in certain cases. In addition, the vulnerability and consequences associated with hazards may increase as hazard severity grows, which affects the selection and implementation of disaster mitigation strategies. Following are some suggested disaster mitigation strategies for emergency managers to consider with respect to climate change.

ADAPT CURRENT DISASTER MITIGATION STRATEGIES TO CLIMATE CHANGE IMPACTS

Current disaster mitigation strategies will need to evolve over the short-, medium-, and long-term to continue to lessen the consequences of actual disasters. Island and Atlantic coastal communities, for example, might be facing more frequent and/or severe hurricanes in the next 10 to 40 years [7]. These communities may need changes in strategies and policies related to land use planning and zoning regulations, environmental laws, building codes, tax/insurance incentives such as business interruption insurance and homeowner's insurance, and coastal wetlands rehabilitation. In addition, communities may need to review and change water resources strategies and flood plain management. For example, those communities with combined sewer systems may face an increase in sewage overflows and associated waterborne disease outbreaks as a result of flooding. This could be mitigated by developing improved and hardened sewer systems.

As another example, severe winter storms, heat waves, and tropical cyclones often acutely impact transportation and energy infrastructure and result in considerable resource expenditures to fix roads and restore power as quickly as possible. In regions known to be at a higher risk for heat waves or severe storms, officials can prepare by reinforcing the transportation and energy infrastructure in key areas, as well as setting up out-of-state and private contracts for heavy equipment and repair services. These issues should continue to be factored into State and local mitigation planning efforts that are led by and required of emergency management agencies.

ENGAGE PROACTIVELY WITH REGIONAL CLIMATE RESEARCH GROUPS FOR DATA TO SUPPORT THE HIRA PROCESS

Analytically rigorous risk assessments are a critical step to informing disaster mitigation and preparedness activities with as much confidence as possible. However, clear and precise assessments of the likely climate-induced changes in the frequency and occurrence of natural and hazards are not readily available. To improve hazard data availability in the future, the emergency management community could proactively engage climate change organizations, non-governmental organizations, academic institutions and working groups as stakeholders in the HIRA process. Several national assessments have been conducted by government and non-government groups, including the U.S. Geological Survey, the National Oceanographic and Atmospheric Administration, and the Pew Center on Global Climate Change, which include information on regional-level impacts of climate change. In addition, many State and local climate research groups exist and may provide a source of data and analytical methods suited to specific geographic areas or hazard patterns. For example, the California Climate Change Center at the University of California at Berkeley conducts detailed studies on the expected impacts of climate change on California. Reaching out to these national and regional climate change groups could help refine the hazard data used to support the HIRA process and improve the analytical results that it generates.

COORDINATE WITH REGIONAL PLANNING GROUPS TO SUPPORT THE HIRA PROCESS AND DEVELOP REGIONAL MITIGATION STRATEGIES

The effects of climate change may create risks that are more regional in nature in that they affect a broader geographical area or require resources from a larger community of partners. Regional risks are inherently more complex and demand joint approaches for managing them. Managing regional risks requires collaboration among a broader set of players than smaller-scale local response. By their very nature, regional risks require multiple communities to work together because no one jurisdiction can be expected to handle the regional risks alone. These collaborative activities involve a very diverse set of stakeholders that represent the broader size and composition of the region and also include State, Federal, private sector, and nongovernmental organizations. Effective relationships have to be built with expanded requirements in mind, nurtured through deliberate and sustained planning initiatives, and tested through exercises to identify planning gaps before events occur.

More than likely, the contours of the regions impacted by these new hazard patterns will not coincide neatly with existing political divisions, such as FEMA regions, State lines, or international borders. However, the existing FEMA regional structure offers an established and tested administrative mechanism through which FEMA can energize a regional climate change and preparedness dialogue that helps stakeholders rethink, where applicable, our collective approach to disaster mitigation. FEMA can leverage its regional presence to bring together relevant Federal agencies, State, local, private sector, non-governmental organizations, academics, and existing regional climate change groups to address the implications in natural hazard patterns and develop regional disaster mitigation strategies. These discussions could yield important insights on structural improvements to existing disaster mitigation programs and evolution of disaster mitigation planning at all levels of government. FEMA should also strengthen its international partnerships with Mexico, Canada, and Caribbean nations. The success of planning models like FEMA's New Madrid Seismic Zone Catastrophic Earthquake Disaster Response Planning Initiative and FEMA's Regional Catastrophic Grant Program (RCGP) may offer insights on potential approaches for innovative disaster mitigation and preparedness activities for managing climate change.

Preparedness

Changes in hazard frequency and severity will have tremendous impact on preparedness activities, such as planning, training, and exercising. Below are some suggested preparedness strategies for emergency managers to consider with respect to climate change.

Preparedness Activities Must Adapt to Climate Change

Over time, planning assumptions in operational plans may need to be adjusted to account for the changing risk profile and the associated vulnerabilities and consequences. As the HIRA process is updated to incorporate climate change impacts, follow-on activities must also adapt. For example, emergency managers may need to do the following:

- Re-examine their planning scenarios and assumptions to address an increase in frequency and/or severity of a given natural hazard.
- Re-address their capability assessments to account for changes in their risk profiles. Further, they may need to re-examine their capability gaps to determine whether additional resources are required.
- Develop additional training packages for their personnel to address changing requirements.
- Invest in additional or alternative exercises to examine whether their plans and procedures are sufficient for more severe or frequent natural hazards.
- Identify both traditional (e.g. oil refinery plants) and emerging (e.g. solar panel and wind turbine farms) critical infrastructure that may be impacted by more frequent and/or more sever natural disasters and assist them with the development of emergency and continuity of operations plans.

The implementation of many of these activities is allowable under existing all-hazards preparedness grant programs or mitigation planning programs. However, the Federal Government may also wish to explicitly call out climate change adaptation planning as an allowable cost in order to help draw the explicit connection among emergency management, preparedness, and the impact of climate change on these activities.

ENCOURAGE EMERGENCY MANAGEMENT INCLUSION IN STATE AND LOCAL CLIMATE CHANGE ADAPTATION PLANNING PROCESSES AND STRATEGIES

Climate change and adapting to its consequences are gaining momentum as key planning concerns for States and local government. For example, a recent report on the impact of climate change on public health noted that thirty-three States had published a strategic plan on climate change and twenty-six had established advisory panels or commissions on climate change [16]. Several State action plans are also focused on reducing greenhouse gas emissions.

The emergency management community should be included in these and other adaption planning processes and in developing climate change mitigation and adaptation strategies at the local, State, and regional levels. Energy, health, agriculture, environment, and natural resource agencies at all levels of government have obvious roles to play in these planning initiatives, working to slow the onset of climate change impacts through innovative policies and to prepare for potential consequences. Given the leadership role emergency managers play in coordinating disaster management activities and in understanding the hazards facing States and localities, they should also have a seat at the table in long-term adaptation planning. However, the State or local agency with lead responsibility for climate change policy development and implementation may not currently see emergency management agencies as stakeholders in the process. The potential role of emergency management in the climate change policy framework, the technical value of its inclusion, and the impact of climate change policy on emergency management program implementation must be explained clearly and communicated widely in order to ensure that emergency management participate in adaptation planning.

CONSIDER THE IMPACTS ON VULNERABLE POPULATIONS

Changes in hazard profiles will particularly impact socially vulnerable populations [17]. Therefore, emergency managers will need to better understand the potential impacts of increasingly frequent and/or severe hazards on the at-risk populations within their communities. For example, heat waves can cause death and heat-related illnesses like heatstroke and heat exhaustion, largely in the elderly and economically disadvantaged residents in urban areas. Emergency managers need to ensure that these factors are understood and included in operational plans that address warning, evacuating, and sheltering at-risk populations. Emergency managers should also develop communication and education programs to educate the public and vulnerable populations (especially for limited English proficiency communities) about the potential effects of climate change on their communities and their health.

INCORPORATE INFORMATION ON THE EFFECTS OF CLIMATE CHANGE INTO EXISTING COMMUNITY PREPAREDNESS CAMPAIGNS

If hazards are more frequent and severe, and local resources are increasingly strained, the 72-hour rule of self-sufficiency for the public may not be adequate. Emergency managers need to consider how they will manage the expectations of the community about what the government will and won't be able to provide them within 72 hours after a disaster. For successful messaging, the public needs to understand that climate change is real and that it can affect them in direct ways. Because personal preparedness will become even more important, emergency managers must have an honest dialogue with the public about realistic service expectations.

RESPONSE

Response operations may become more complex as local resources are overwhelmed by more severe and more frequent hazards. Mutual aid among agencies within a community and among States will probably be called upon with greater frequency. If natural hazards become more frequent and/or more severe, it becomes more likely that traditional mutual aid partners are not able to support mutual aid requests as they have in the past. Operationally, this could mean that disaster responses may start to routinely include more personnel from a wider array of State and Federal agencies, which will increase the costs at all levels of government. The following are some suggested response strategies for emergency managers to consider with respect to climate change.

DEVELOP MODELS TO ESTIMATE THE FINANCIAL IMPACT OF LARGER AND MORE FREQUENT RESPONSE OPERATIONS ON LOCAL BUDGETS

More frequent and more expansive response operations will exhaust local resources quickly. They will also strain existing budgets and staff. The emergency management community should adapt current cost-estimate models to identify potential costs and help frame budget requests, requirements, and tradeoffs downstream. The models should also take into consideration the economic impact of climate change on businesses and the greater community. This will help emergency managers better understand the potential scale and impact of climate change on their local community and region. The emergency management community may want to customize these models by region to account for any unique issues that may be applicable.

ANTICIPATE COMMAND AND CONTROL CHALLENGES

After-action reports from large-scale exercises and real-world events consistently highlight command and control as a challenge that faces everyone involved. With the release and evolution of the National Incident Management System (NIMS) over the past 5 years, the U.S. has made tremendous progress in developing and using a standardized structure for incident management that leverages the widely understood principles of the Incident Command System (ICS). However, exercises and real-world events have demonstrated challenges associated with scaling NIMS to truly large-scale, national events. The response to events like Hurricane Katrina and major national exercises like the Top Officials (TOPOFF) series confirm the challenges of establishing unified command at incident sites where responding entities arrive with different authorities, missions, and functions. Moreover, they illustrate the complexity of connecting command and control nodes that can span from the incident site itself all the way up to the White House.

The potential for more severe and more frequent disasters of increasing complexity and geographic scale provides a healthy opportunity to step back and review the lessons we have identified through exercises and past disasters on command and control failures. That potential may also merit the introduction of fresh ideas into incident management doctrine from network analysis and field operations on ways to decentralize command and control in major disasters. For example, lessons learned by the military in managing complex operations certainly do not translate automatically into the world of civilian incident management because the chain of command and legal frameworks are altogether different. However, there may be opportunity to objectively review some practices employed by the military to see if they can be refined and adopted in ways that strengthen civilian management of complex incidents. At the very least, with the likelihood of more frequent and severe disasters on the horizon, the emergency management community can lead the effort to act on the command and control lessons that have been learned through past experience.

Recovery

More severe hazards imply that more homes and businesses are damaged, which will make recovery efforts more complicated. This will be particularly true if disaster mitigation measures are not aggressively implemented ahead of time. More frequent hazards could also mean that another incident may occur before recovery efforts from the previous disaster have finished. The following are some suggested recovery strategies for emergency managers to consider with respect to climate change.

Increase the Efficiency of the Recovery Process

Recovery planning is already a recognized gap in emergency management based on lessons learned from Hurricane Katrina and other large-scale exercises. This phase takes a long time to complete, is not owned by a single government entity, and can stretch government and non-government bodies beyond their traditional missions into new areas outside their core competencies (e.g., consider emergency management agencies managing long-term housing needs). Key national strategies, plans, and guidelines have been developed for other homeland security mission areas like prevention, protection, response, and preparedness, but recovery remains an outlier. The newly formed Long-Term Disaster Recovery Working Group, led by the Departments of Homeland Security and Housing and Urban Development,[6] is a first step toward addressing that gap. State and local governments must also intensify their efforts to plan for the recovery phase of major disasters on a more frequent basis.

6. http://disasterrecoveryworkinggroup.gov/

The potential for more frequent and severe disasters puts a premium on increasing efficiency in recovery operations. Developing recovery plans and testing them through exercises will be vital to meeting the growing needs of disaster survivors in future events.

Consider the Criteria for Decisions to Rebuild Post-Disaster

An increase in the frequency and severity of selected natural hazards in a local community or region will require communities, including emergency management officials, to make extremely difficult policy decisions about when not to rebuild in certain areas. In some instances, the question will be about how to rebuild differently to ensure that any new construction is stronger and more resilient. In other instances, rebuilding may no longer make economic sense, particularly when viewed within the context of sustained, long-term shifts in hazard patterns induced by climate change. This issue has begun to surface in discussions of recent hurricane events and their impact on certain communities such as low-lying areas in New Orleans that were devastated by Hurricane Katrina and Galveston, Texas, which was devastated by Hurricane Ike. The emergency management community should consider developing decision criteria to help in this very difficult decision-making process, based on a policy determined in an analytical and rigorous manner. Such policy decisions could be implemented in State and/or local land use, zoning, environmental laws, and building codes.

Incentivize Self-Sufficiency and Rapid Essential Service Restoration in the Private Sector

The economic impact of a disaster will be lessened and the recovery process eased if the private sector can return to normal quickly following an event. Consider the economic and psychological benefits to the community if residents procure water, ice, and food from their usual grocery stores rather than from a government-organized relief center. Doing so requires businesses that provide essential services to prepare themselves for disasters, acknowledge that they are lynchpins in the recovery process, and accept a responsibility to the public for helping communities rebound. Incentives for rapid restoration can be considered in zoning and tax codes. Emergency management can support that process, helping to identify essential service providers before events happen and to integrate them into relevant planning processes and exercises.

Conclusion

Our review of the climate change literature revealed two broad trends: an increase in frequency and an increase severity for selected hazards. Some disasters, such as hurricanes, will likely happen with greater frequency and severity in places they already occur. Other disasters, such as urban wildfires in the Pacific Northwest, may occur in areas that have not historically experienced them on a regular basis. Overall, these two trends lead to a decrease in the ability of the current HIRA models to produce accurate hazard predictions.

For natural hazards, the HIRA process is largely based on historical occurrence. However, given the changing patterns in the frequency and severity of these hazards, historical data may not accurately forecast future events. Therefore, climate change data must be integrated into the HIRA process, and the disaster mitigation, preparedness, response, and recovery activities that it informs across all levels of government.

Analysis of these hazard shifts allows regions to incorporate emerging challenges into planning cycles and to build response capabilities accordingly. This is further an opportunity to utilize the measured and deliberate processes already established in the emergency management community of risk analysis, disaster mitigation, and preparedness efforts to arm communities against these shifting hazards.

Appendix: Effect of climate change on selected hazards

A summary of our analysis of each hazard is provided in this appendix. Each section includes a historical summary of the hazard in the U.S. over the last 10 years, in terms of incidence and severity; a discussion of the responsibility of emergency management agencies; and a review of the climate change research with respect to that hazard. Together, these three sections are intended to provide emergency managers and policy makers with an understanding of the consequences that an increase in severity and/or frequency of selected natural hazards could have on disaster mitigation, preparedness, response, and recovery strategies.

Tropical cyclones

For this report, we identified the tropical cyclones that threatened the U.S. mainland and territories over the last 10 years. We include strikes as well as landfalls because many tropical storms and hurricanes that do not make actual landfall nonetheless elicit a response from local, State, and Federal emergency management agencies.

Historical incidence

Between 1998 and 2007, a total of 53 tropical storms and hurricanes made landfall on or struck the U.S mainland or a territory. The number of tropical storms and hurricanes per year is shown in Figure 3, along with the number of associated FEMA disaster declaration. Thirty of these storms were tropical storms, and 23 were hurricanes, of which nine were classified as major hurricanes (Category 3 or higher) [18,19]. Sixty-five FEMA disaster declarations were issued for 33 of the tropical cyclones [20], which implies that multiple declarations were issued for the same storm. For example, Federal declarations were issued for counties in North Carolina, Virginia, Maryland, Washington D.C., West Virginia, Delaware, and Pennsylvania in response to Hurricane Isabel in 2003. Interestingly, of the 65 disaster declarations that were issued, 22 were for areas not impacted by the storm for which they were issued. For example, Hurricane Isabel did not pass through Maryland, Washington D.C., or Delaware. This indicates that historically pre-emptive declarations for particular regions were issued in anticipation that a tropical storm or hurricane would strike.

We examined the number of fatalities and amount of property damage as a measure of severity. The number of fatalities and amount of property damage per year are shown in Table 1. Between 1998 and 2007, tropical storms and hurricanes resulted in a total of 1,168 fatalities and $127.9 billion in property damage. It should be noted, however, that the significant majority of fatalities and a large percentage of total property damage – 1,016 and $93.1 billion, respectively – occurred during 2005, which included Hurricanes Katrina and Rita [21].

Figure 3. Number of tropical cyclones and disaster declarations by year, 1998-2007

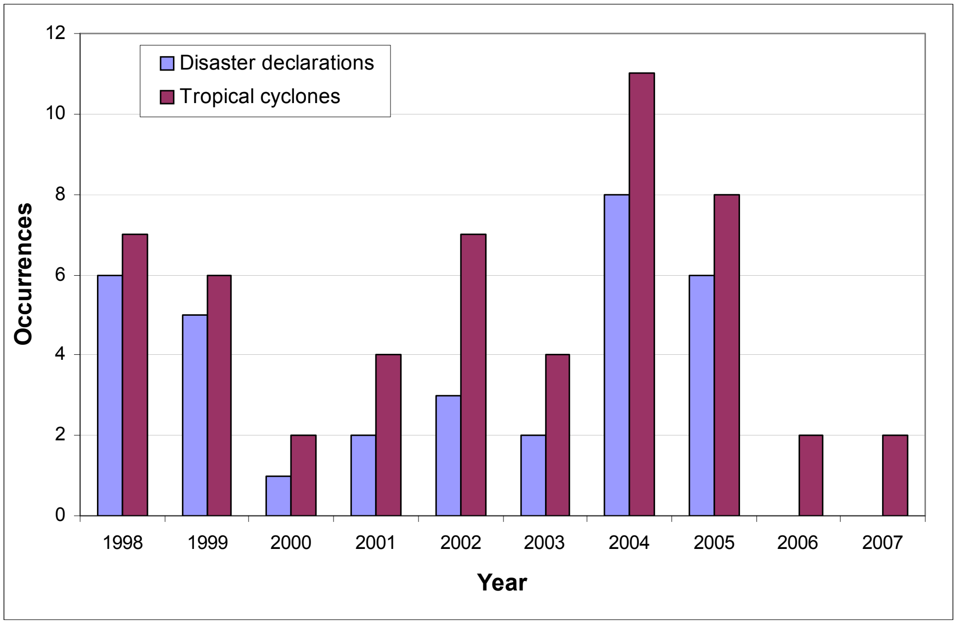


Table 1. Fatalities and property damage due to tropical cyclones by year, 1998-2007

Year	Tropical Cyclones	Fatalities	Property Damage ($ billions)
1998	7	9	3.547
1999	6	19	4.190
2000	2	0	0.008
2001	4	24	5.188
2002	7	51	1.104
2003	4	14	1.880
2004	11	34	18.902
2005	8	1016	93.064
2006	2	0	0.002
2007	2	1	0.039

Role of emergency management

When a tropical cyclone is projected to strike or make landfall, all emergency management agencies from all jurisdictions--local, State, and Federal--within the affected region are directly involved in the response. For example, several practical steps were enacted by local officials in Texas in anticipation of Hurricane Ike's arrival in September 2008. The Governor issued a preemptive disaster declaration for 88 counties on September 8, 2008, 5 days prior to landfall. The Texas National Guard assisted in the advance evacuation of special needs residents. To prepare for a potential mass evacuation, shoulders of major highways were cleaned up and cleared of debris so they could be used as additional lanes, and construction projects were cancelled to prevent unnecessary obstacles or delays to evacuees. Courtesy trucks were stocked with fuel for stranded motorists so they could make it to the next filling station in order to prevent them from blocking traffic [22, 23].

The Texas Department of Public Safety opened Disaster District Operations Centers while the Texas Forest Service staffed a resource staging area and pre-positioned five incident management teams. The Texas Department of Agriculture prepared to distribute food and began coordinating its efforts with the American Red Cross and the Salvation Army. Additionally, they enacted plans to protect livestock in the path of the expected storm. The Emergency Management Council and State Operations Center were fully activated days before Ike arrived, coordinating extensively amongst State agencies [22,23].

Voluntary and mandatory evacuation orders for both the general population and special needs population across the region were first issued on the morning of September 10th. Shelters were also opened across the State for both the general and special needs population. A Federal disaster declaration was issued on September 10th to allow for the movement of Federal assets to the Houston-Galveston area [22,23].

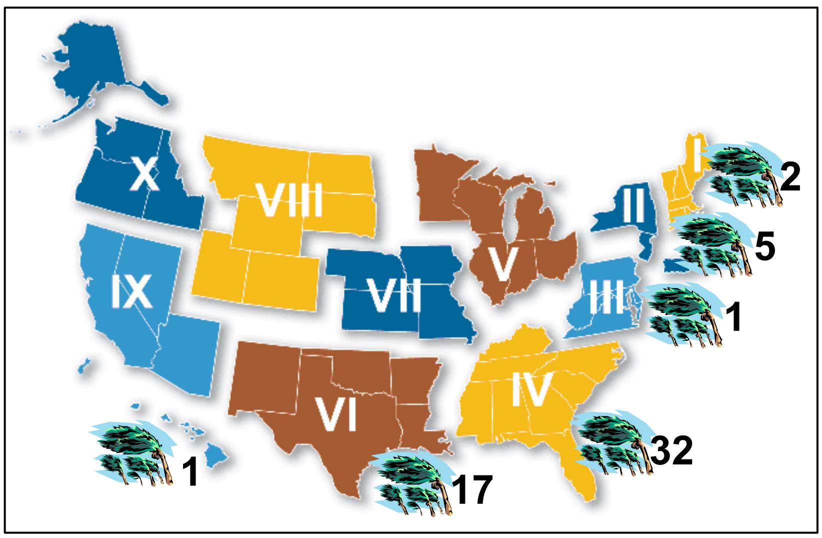
Power and phone outages began before Hurricane Ike made landfall. Power outages caused water plants to become inoperable, and boil-water orders were issued across the region. Recovery efforts went into full effect September 13th 2008. After the passing of the storm, local, State, and Federal search and rescue teams were quickly deployed and emergency debris clearance operations began. While debris was being removed, power companies quickly went to work trying to restore power to an estimate 3 million customers left without power. As Federal assistance came into the State, funds were distributed to assist with debris removal, emergency protective measures, road systems and bridges, water control facilities, housing, buildings, contents and equipment, utilities, parks and recreation, and State management [22,23].

Impact of climate change

Tropical storm and hurricane data across decades indicates that there has been considerable variability in tropical cyclone activity, with a period of above-average activity since 1995 [7,8,24,25]. Interdecadal variability aside, there are indications in the literature that warmer temperatures will impact tropical cyclones. Drawing upon sea surface temperature (SST) and Category 4 and 5 hurricane data between 1970 and 2004, the *U.S. Global Change Research Program* report highlights a study that identifies a direct correlation between SST and an increase in Category 4 and 5 hurricanes [8,26] In the same study, the research indicates that during the past 30 years, annual SST in the main Atlantic hurricane development region increased nearly 2°F, coinciding in particular with an increase of intensity and frequency of Category 4 and 5 hurricanes [8]. It is important to note, however, that several other factors (which have been studied to a much lesser extent than SST) affect hurricane intensity, such as atmospheric stability and circulation [8]. Therefore, while exact predictions are not available, it is likely that Cate gory 4/ and 5 hurricanes will increase in the near future.

FEMA Regions II, IV, and VI have historically been most susceptible to tropical cyclones, as shown in Figure 4.[9] According to the climate change literature, States along the Gulf and Southeast coasts, as well as islands in the Caribbean are projected to be most affected by climate-induced changes in hurricane activity in the future [7,8]. While these regions are accustomed to tropical storms and hurricanes, increases in storm intensity will further test community defense systems such as levies and other barriers, as well as emergency services and multijurisdictional coordination with regard to evacuation and sheltering. As we saw during Hurricane Katrina, which was only a Category 3 storm at landfall, evacuation and sheltering are complicated operations, and we should expect these operations to become more difficult to carry out during more severe storms.

Figure 4. Tropical cyclones making landfall or striking the U.S., 1998-2007[8]



8. There is a discrepancy between the number of total tropical cyclones (53) and the number of total tropical cyclones by region (58) because on three occasions tropical cyclones impacted more than one region. Specifically, two storms impacted two regions, and one storm impacted four regions.

9. We include FEMA Region II in this list since Region II is responsible for U.S. territories in the Caribbean, such as Puerto Rico and the U.S. Virgin Islands, which are also susceptible to tropical cyclones.

URBAN WILDFIRES

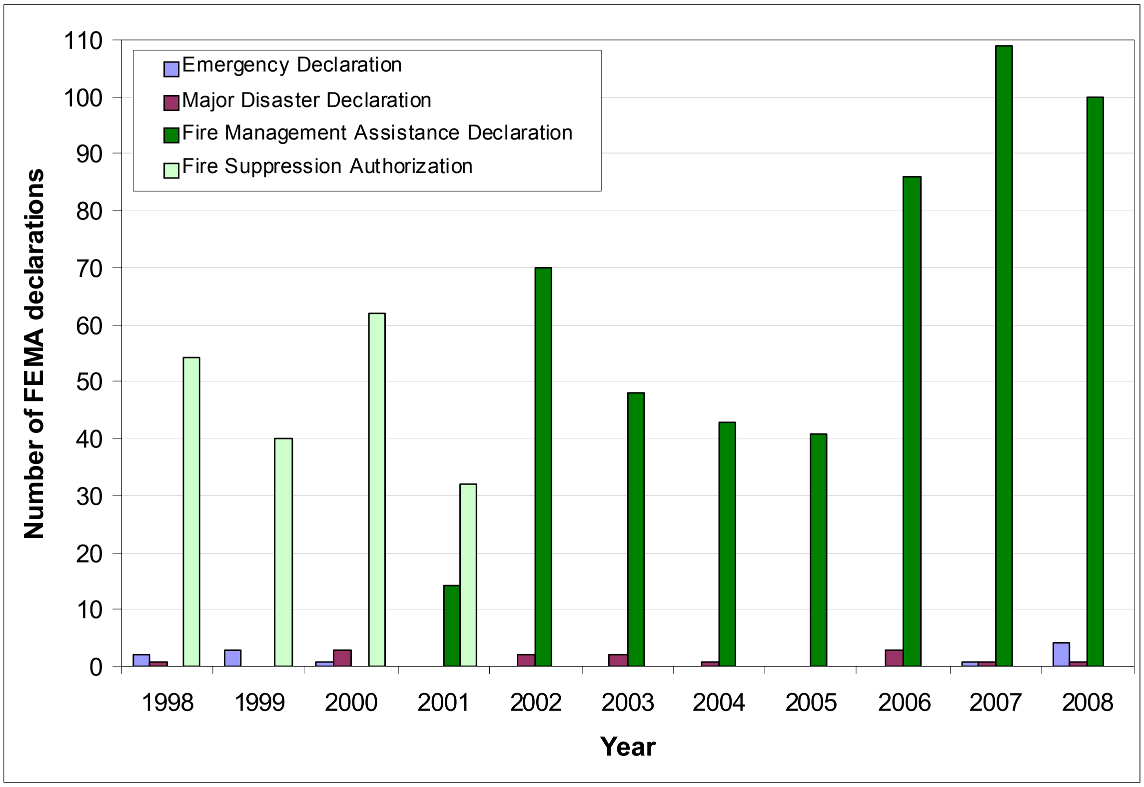
We began our review of wildfires by focusing on the data used in the U.S. Department of Agriculture (USDA) and U.S. Department of the Interior's (DOI) definition for wildfires, which includes all unplanned, non-structure fires occurring in the wildland. There are wildfires that are typically caused by lightning, volcanoes, and unauthorized and accidental human-caused fires, to include prescribed fires that go awry. This is distinct from structure fires that occur in urban or controlled environments and are the accidental or intentional result of human activities. However, given that we are interested in the impact of wildfires on emergency management agencies, we narrowed our focus to include only those fires that occurred at the wildland urban interface – the space where wildlands (and fires, when they occur) intersect communities [9]. In order to capture the frequency of fires that occurred at the wildland urban interface, we identified those wildfires that qualified for a FEMA declaration. These include a FEMA Fire Suppression Authorization Declaration, a FEMA Fire Management Assistance Declaration, a FEMA Emergency declaration, or a FEMA Major Disaster Declaration. By definition, a FEMA Fire Management Assistance Declaration (and a FEMA Fire Suppression Authorization Declaration when it was issued[10]) makes Federal funding available to local jurisdictions in fighting wildfires that threaten to cause a major disaster. The declarations cover 75 percent of select firefighting costs, including expenses for field camps; equipment use, repair and replacement; tools, materials and supplies; and mobilization and demobilization activities [27]. Further, FEMA Emergency and Major Disaster declarations issued in response to a wildfire typically provided support to State and local communities impacted by large wildfires.

Historical incidence

Between 1998 and 2007, a total of 801,249 wildfires in the U.S. burned a total of 65.1 million acres. [28]. Of those wildfires, there were only 724 FEMA-designated declarations–699 Fire Suppression Authorization or Fire Management Assistance declarations and 25 Emergency or Major Disaster Declarations [29]. Figure 5 shows the breakdown of FEMA-designated wildfires per year.

10. FEMA Fire Suppression Authorization Declarations were issued until October 1, 2001; since then, Fire Management Assistance Declarations have been issued and provide the same level of Federal assistance.

Figure 5. Number of FEMA declarations for wildfires by year, 1998-2008



Role of emergency management

While the National Interagency Fire Center assumes responsibility for all large wildfires, those that occur at the wilderness/urban interface typically involve local and State emergency management assets. For example, the Jesusita Fire swept through Santa Barbara County in California in May 2009. In total, the fire injured 29 firefighters, consumed 78 homes, damaged another 22 homes, burned 8,733 acres of land, and forced approximately 30,000 people to evacuate the area [30,31]. Although small in terms of acreage burned, this incident is informative for the role of emergency management agencies when wildfires affect urban areas.

The wildfire began on May 5th as a brush fire. Initially several fire engines and a battalion chief from Santa Barbara City Fire Department responded, which was standard protocol for a brush fire. Due to the fire's rapid growth, additional resources from the Fire Department and Santa Barbara County were requested shortly thereafter. In less than an hour, local officials ordered mandatory evacuation for nearby residents. As it quickly became clear that local resources would be insufficient, the fire was declared a major incident and assistance was requested through California Master Mutual Aid making use of the Resources Ordering Status System [30,31].

Law enforcement personnel knocked on the doors of approximately 1,200 homes the first day of the fire to notify residents of a mandatory evacuation [30]. The Sheriff's Department worked with representatives from 20 outside agencies from three different counties to conduct patrols, perimeter maintenance, and evacuation assistance [32].

The American Red Cross responded by opening a shelter within approximately two and a half hours of the outbreak of the fire. The first night, it provided a place to sleep for 10 people. On the third night of the fire, due to the increased number of evacuees, the Red Cross opened a second shelter. In addition to people, large animals were offered shelter at the Earl Warren Showgrounds and more than 500 other animals were cared for by the Santa Barbara Humane Society at emergency shelters [30,31].

At 6 p.m. on May 6th a State official from the California Department of Forestry and Fire Protection (Cal Fire) took over from the local officials to organize a more robust response. Cal Fire has 10 incident command teams across the State and is set up to provide equipment, personnel, and resources to any area in need. Shortly thereafter, the Governor proclaimed a state of emergency in Santa Barbara County, opening up the possibility to receive Federal funds. The Governor also announced that they were coordinating with the National Guard in case there was a shortage of personnel [30,31].

On May 7th FEMA issued a Fire Management Assistance Declaration, which authorized the use of Federal funds to assist California State and local firefighting agencies in fighting the Jesusita wildland Fire. Santa Barbara County opened a Local Assistance Center on May 18th to provide aid to fire victims from a variety of government agencies and nonprofits, including the Department of Insurance and the IRC. On the same day, the county hosted a Fire Recovery meeting to address debris removal and other issues [27,30,31].

Impact of climate change

The climate change literature is in agreement that forest fires are expected to increase in frequency, severity, distribution, and duration, as a result of overall warming temperatures, earlier spring thaws, and an increase in the likelihood of periodic and intense droughts [8,10,11,12]. These changes can be explained by the confluence of higher concentrations of atmospheric carbon dioxide, longer summers, more precipitation leading to wetter conditions, and an increase in drought-like conditions. In simple terms, an increase in atmospheric carbon dioxide and longer growing seasons will lead to an increase in woody vegetation, which serves as fuel for wildfires. Given climate variability and the increased chance for periodic and intense droughts, this buildup of fuels will increase the likelihood of wildfires [12].

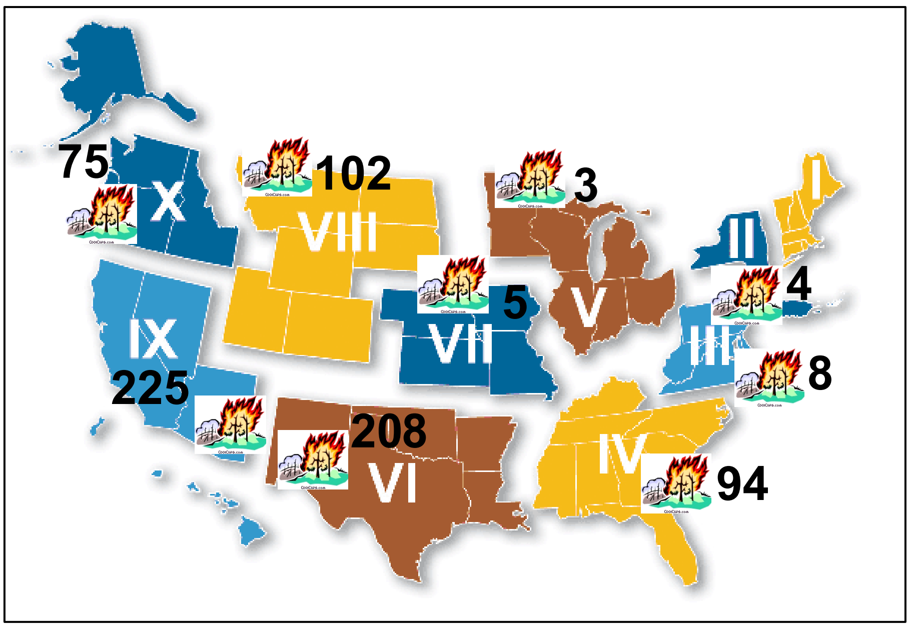
Although changes in climate may increase the likelihood of more frequent and/or more severe wildfires, it is difficult to predict the impact of climate change on wildfires since they are regional events affected by regional climates, and predicted changes in climate are typically discussed in broad rather than region-specific terms [33]. Some areas may see an increase in wildfires while other areas may see a decrease [34,35,36]. In other words, despite agreement that parts of the United States will undergo a general drying in the future, which increases the likelihood of wildfires, seasonal and regional changes in precipitation patterns make it hard to predict when and where wildfires will occur [37].

Despite the difficulties in predicting how climate change will affect the way in which wildfires occur, some region-specific predictions are available. According to the climate change literature, wildfires could increase in the western, northwestern, and southwestern U.S. [8,10,11,12]. Studies focused on the southwestern U.S. suggest that fire severity could increase by 10 percent [10]. This projected increase in wildfire severity is also supported by precipitation projections, which generally suggest that the West will experience drier summers in the future [38].

The western and southwestern U.S. regions have historically been most susceptible to wildfires, as shown in Figure 6. This is in line with the region's weather and wildfire trends in recent decades, where earlier spring snowmelts and hotter, drier summers have led to an increase in the number and duration of large wildfires [37]. In addition, the climate change literature suggests that temperatures could increase in the southeast region of the U.S., which is a strong indicator for an increase in wildfires [8]. This region has also historically seen a large number of urban wildfires over the last 10 years. While these regions are accustomed to wildfires, increases in severity and/or frequency could further strain local emergency services and increase recovery costs if more people move into wildfire-prone areas.

Interestingly, the climate change literature also suggests that wildfire activity in the Pacific Northwest could increase. While this region has seen some urban wildfires, they have been less frequent than those in the Southwest or Southeast. Therefore, wildfires could become an emerging threat for the region, especially if the population density within the wildlife urban interface increases. A similar threat is also emerging for urban centers in Alaska, where large wildfires are already common [8,39].

Figure 6. Urban wildfires across the U.S., 1998-2008



Floods

We used the NOAA National Climate Data Center's classification for floods where flash, river, coastal, urban, and small stream floods are reported as "events," each of which impacts one or more counties.[11] For example, torrential rainfall resulting in flash flooding in three counties could be counted as one, two, or three flood events, depending on the location of the counties and ultimately, how the flood event(s) are reported through NOAA.[12]

For this study, we tracked flash, river, coastal, urban, and small stream flood events resulting in at least $1 million in property damage over the last 10 years, as reported by NOAA. Hereafter, these flood events will be referred to as "large flood events" to indicate that we are only considering those that meet our threshold (i.e., causing at least $1 million in property damage), not total floods.

Historical incidence

Between 1998 and 2007, there were 1,435 large flood events, resulting in 263 fatalities and $132.2 million in total property damage [40]. Figure 7 shows the breakdown of large flood events per year, as well as the breakdown of floods that received a FEMA disaster declaration (both major disaster and emergency declarations) [20]. It is important to note that the number of large flood events in a given year does not necessarily correspond to the number of FEMA declarations. For example, a large flood event that covers multiple counties would receive only one FEMA declaration, but would generate multiple NOAA reports. In addition, there are some FEMA disaster declarations that encompassed hazards in addition to flooding that occurred during the same event (e.g., flooding, landslides, tornados). On the other hand, this could also signify that some large flood events did not meet the criteria for a Federal declaration.

We also examined the number of fatalities and property damage as a measure of severity. The number of fatalities and amount of property damage per year are shown in Table 2. Between 1998 and 2007, large flooding events resulted in a total of 263 fatalities and $17.4 billion in property damage.

11. We did not consider flooding as a result of global sea rise, because that was outside the scope of this report.
12. While this definition is somewhat loose, it is worth noting that tracking floods and many weather events generally is an inexact science since it is sometimes difficult to determine when and where one event ends and another begins.

Figure 7. Large flood events and FEMA declarations by year, 1998-2007

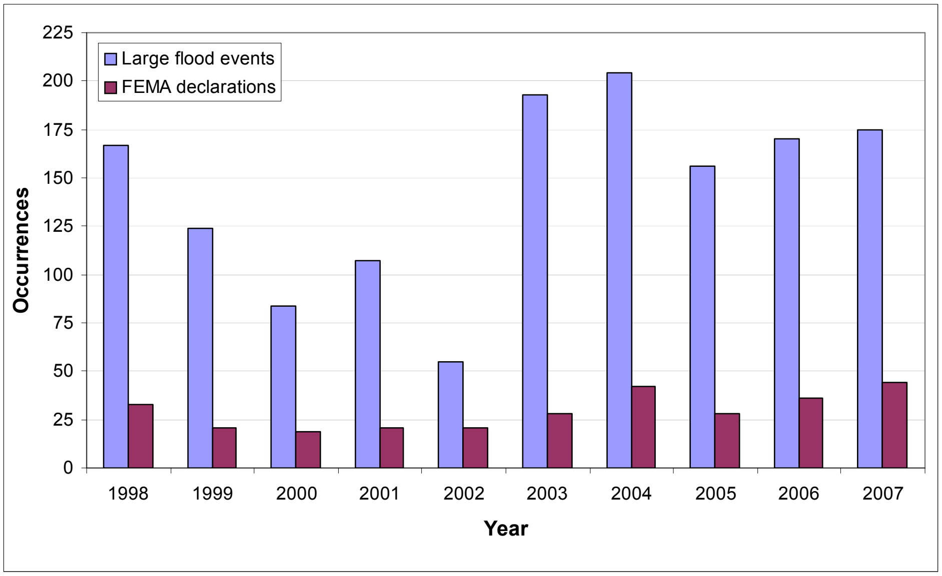


Table 2. Fatalities and property damage from large flood events by year, 1998-2007

Year	Tropical Cyclones	Fatalities	Property Damage ($ billions)
1998	167	82	2.292
1999	124	22	1.348
2000	84	11	1.160
2001	107	15	1.146
2002	55	13	0.583
2003	193	32	2.424
2004	204	29	1.576
2005	156	15	1.424
2006	170	21	3.818
2007	175	23	1.662

Role of emergency management

There are numerous examples of large flood events over the last 20 years, including the Great Flood of 1993, which affected States along the Mississippi River, flooding in the South-Central U.S. in 1995, flooding in the Pacific Northwest and Montana in 1997, floods in North Dakota and Minnesota in 1997, flooding in the Mid-Atlantic States in 2006, flooding in Missouri in 2007, and flooding in Iowa in 2008. Here we highlight the Missouri 2007 flood to illustrate the role of local, State, and Federal emergency management agencies during a large flood event.

In a 24-hour period, from May 7th to May 8th, 2007, the National Weather Service reported that parts of Missouri received between 4 and 8 inches of rainfall [41]. The Governor declared a state of emergency, mobilized the National Guard, and activated the State Emergency Operations Center (SEOC) on May 7th. By May 9th, at least 20 levees were reported topped, highways were forced to close, and thousands of people were evacuated [42].

On May 8th, Coast Guard Disaster Assistance Response Teams were mobilized and dispatched to Jefferson City to monitor the situation and assist if necessary. In the end, their services were not required. Similarly, the Air Force readied four Predator UAVs in case they were needed to help locate stranded flood victims [43,44].

In Big Lake, one of the hardest hit areas after nine local levees were breached, 500 homes were submerged. State Water Patrol officers rescued residents from approximately 30 homes in Levasy after the breach of two levees suddenly cut of escape routes [45].

Hundreds of thousands of sandbags were filled and used to reinforce levees across the State. Much of the work was done by volunteers. The Army Corps of Engineers also assisted with sandbagging and levee work. The Salvation Army assisted by providing food and drink to sandbagging volunteers. The American Red Cross provided shelter assistance to displaced residents in need. The Missouri State Highway Patrol conducted overflights to monitor levees. The Department of Transportation assisted with road closures while the Office of Administration found resources for communities. The Department of Mental Health provided crisis counseling for citizens affected by the disaster and the Department of Social Services (DSS) worked on emergency food and water requests as well as sheltering issues [46].

State officials requested Preliminary Damage Assessments for 33 counties affected by the flood. The State Emergency Management Agency (SEMA) worked with the Department of Health and Senior Services to ship additional tetanus vaccines to areas in need. SEMA, the Department of Natural Resources (DNR), and DSS also worked to provide potable water where needed. In the aftermath of the flood, the Salvation Army provided flood cleanup kits and AmeriCorps sent representatives to local jurisdictions to coordinate long-term recovery projects [46].

On June 12th, the President declared a major disaster in Missouri in response to the May floods. FEMA provided upwards of $5 million to assist in the recovery effort, which includes funding for homeowner loans, small businesses, and State agencies involved in the response. FEMA also provided a liaison to the Missouri State Emergency Operations Center (SEOC) and coordinated Federal agency assistance [47,48].

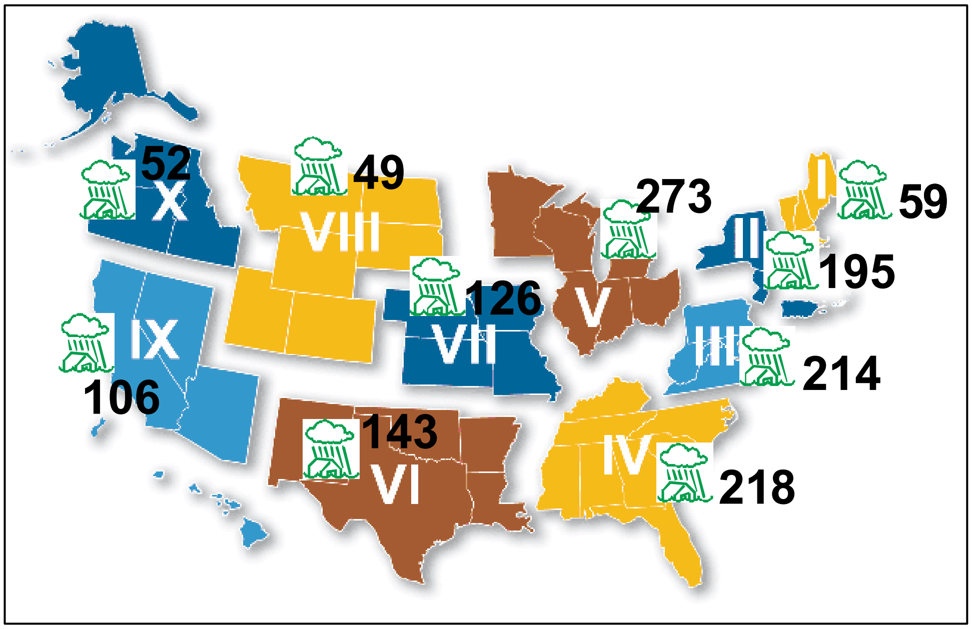
Impact of climate change

Current climate change models predict an overall increase in the amount and intensity of rainfall, but significant shifts in the areas expected to see more or less rainfall [8]. Further, studies also suggest that river flooding may increase due to the projected increase in the frequency of intense precipitation events [8]. This same projection calls for prolonged periods of dryness interrupted by periods of intense precipitation, which means that even areas experiencing infrequent rainfall events are nonetheless at risk for intermittent flooding since rainfall rates may increase during storms [8].

Climate change models, however, cannot accurately predict which areas of the U.S. will see an increase in precipitation and associated flooding events [8,25]. The enhanced hydrological cycle resulting from a warmer atmosphere is expected to yield more heavy precipitation events, but it is difficult to predict which areas across the U.S. will see an increase in precipitation and associated flooding events [8,25].

There have been a substantial number of large-scale floods in all regions, as shown in Figure 8. FEMA Regions II, III, IV, and V experienced more than 60 percent of the large flood events over the last 10 years. Emergency management agencies across the U.S. need to be aware of the possibility of an increased likelihood of flooding in their area. Those regions more accustomed to large flooding are likely better equipped to handle an increase in frequency and/or severity of large flood events. Other regions, which are less accustomed to responding to these events, should begin to consider flooding in their disaster mitigation and preparedness strategies.

Figure 8. Large flood events across the U.S., 1998-2008



Winter storms

We used the NOAA National Climate Data Center's classification for winter storms, where snow and ice storms are reported as "events," each of which impacts one or more counties. For example, a severe winter storm that affected three States could be counted as one, two, or three winter storm events, depending on how those events are reported through NOAA.[13]

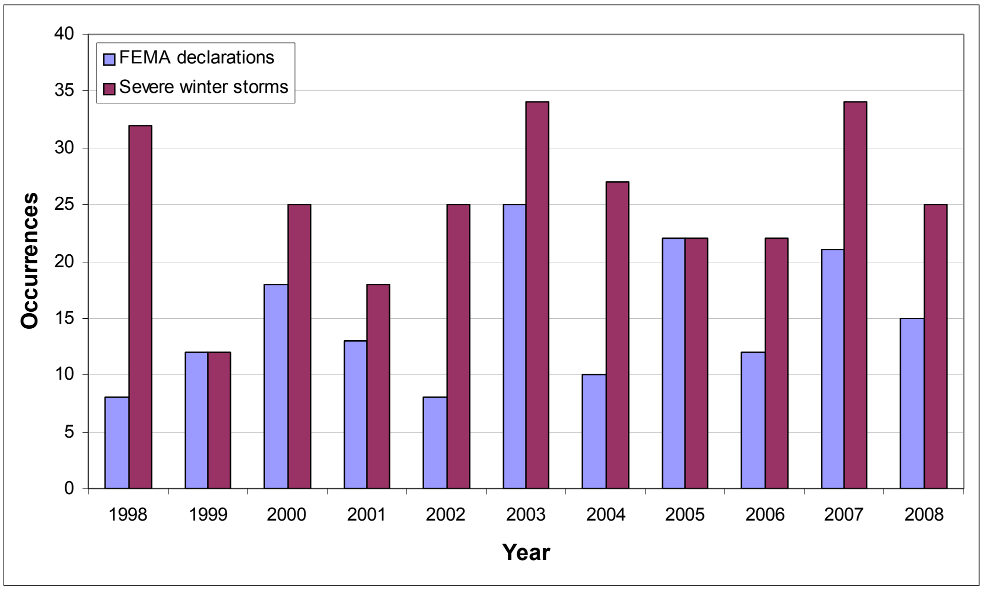
For this study, we tracked winter storm events over the last 10 years resulting in at least $1 million in property damage, as reported by NOAA. Hereafter, these events will be referred to as "severe winter storms" to indicate that we are only considering those that meet our threshold (i.e., causing at least $1 million in property damage).

13. Note that tracking winter storms and many weather events generally is an inexact science since it is sometimes difficult to determine when and where one event ends and another begins.

Historical incidence

Between 1998 and 2008, there were 276 severe winter storms [49]. Figure 9 shows the breakdown of severe winter storms per year, as well as the breakdown of storms that received a FEMA disaster declaration (both major disaster and emergency declarations) [20]. It is important to note that the number of severe winter storms in a given year does not necessarily correspond to the number of FEMA declarations. For example, a severe winter storm that covers multiple counties would receive only one FEMA declaration, but would generate multiple NOAA reports. On the other hand, this could also signify that severe winter storms do not necessarily meet the criteria for a Federal declaration.

Figure 9. Severe winter storms and FEMA declarations by year, 1998-2008



Role of emergency management

There are numerous examples of severe winter storms over the last 10 years. Here we highlight a historic snowstorm in Erie County, New York, on October 12, 2006, as illustrative of the role local and State emergency management agencies play.

By the time the snow stopped falling on October 13th, nearly 2 feet of snow had fallen in Buffalo [50]. Since it was still mid-autumn, trees with all their leaves strained to bear the added weight of the snow. Consequently, the extent of the damage was greater than would have been likely from a later snowfall of the same magnitude.

Thousands of trees were destroyed, and the debris damaged property, blocked roads, and took down power lines. The snow closed schools and roads throughout the county, in addition to shutting down 105 miles of the New York State Thruway for nearly 12 hours [51].

This lake-effect snowstorm caused approximately 376,600 homes and businesses to lose power [52]. The Buffalo News reported that 2,500 utility workers came from approximately 20 States to help restore power in the region [53]. Even with this extra help, however, on October 18th, an estimated 100,000 homes were still without electricity [54]. It took weeks to fully restore power to everyone affected by the storm.

The strain on relief agencies was enormous. The American Red Cross opened six shelters in and around Buffalo, but many shelters and soup kitchens struggled to provide services without power to heat buildings and refrigerate food. In at least one instance, the Army Corps of Engineers provided assistance with generators. The State sent 17 nurses to help local hospitals manage the extra load. The county health commissioner reported that more than 300 people were treated for carbon monoxide exposure, mostly related to the use of generators. Four of the 13 storm-related deaths were from carbon monoxide poisoning [52,55].

The cleanup that followed the October storm lasted well into November. It left behind 2.6 million cubic yards of debris in the city of Buffalo alone [52]. State officials worked with the local landfill to increase tonnage limits and allow more trucks to enter in order to deal with the branches and trees littering the region [56]. Three hundred troops from the National Guard, along with countless volunteers, helped with street cleanup and debris removal. Even with this help, the cost of overtime and private contracts required to clear trees and brush blocking roadways was estimated as high as $150 million for Erie County [52]. The Mayor's office received permission from owners of fairgrounds and a park complex to temporarily store debris. The University of Buffalo also offered space for debris, as well as a staging are for the National Guard. Additional assistance from the University of Buffalo included freezer and refrigerator space for area schools that lost electricity and use of their athletic facilities for high school and community games [57].

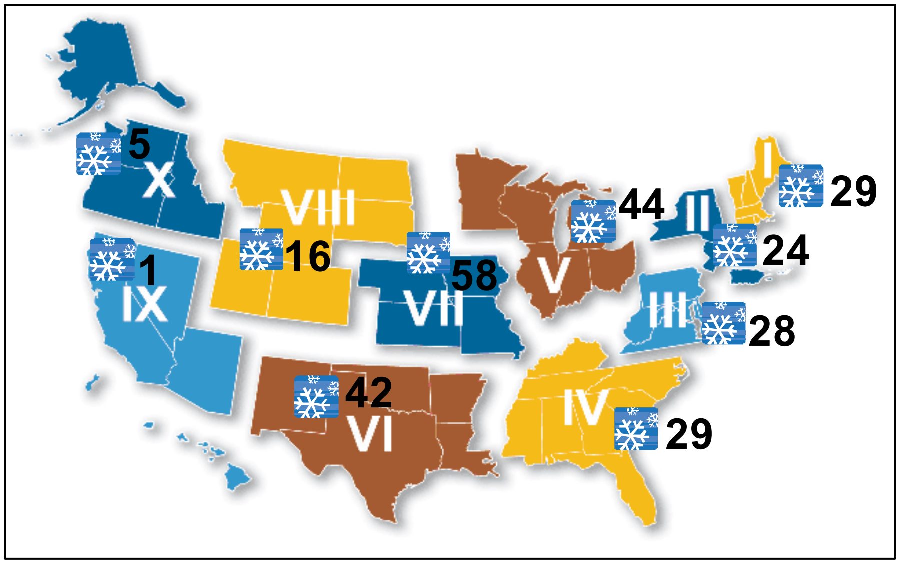
The costs of the snowstorm were considerable. Just paying the overtime needed to Buffalo firefighters and police cost the city $10 million [52,55]. Several days after the snowfall, FEMA announced that it would provide $5 million in relief to local governments. Further, on October 24th, four counties, including Erie, received a major disaster declaration, making additional Federal assistance available [58].

Impact of climate change

According to the climate change literature, the number of lake-effect snowfalls could increase over the next few decades [8]. Lake-effect snow is produced when cold winds move across long expanses of warmer lake water. Warmer temperatures in the winter will lead to less ice on the great lakes, leading to a greater temperature differential and an increase in the likelihood of lake-effect snowfall [8,59].

According to the climate change literature, these regions could experience warmer temperatures in the winter would result in warmer water temperatures on the Great Lakes and other large bodies of water. This could increase the likelihood of more frequent and more severe lake-effect snowfalls. Additional lake-effect snowstorms would further impact local and State emergency management agencies in FEMA Regions I, II, III, and V. Combined, these regions accounted for 125 severe winter storms from 1998 through 2008, as shown in Figure 10. In the event these warming trends continue communities could experience larger impacts on their economies and critical infrastructure.

Figure 10. Severe winter storms across the U.S., 1998-2008



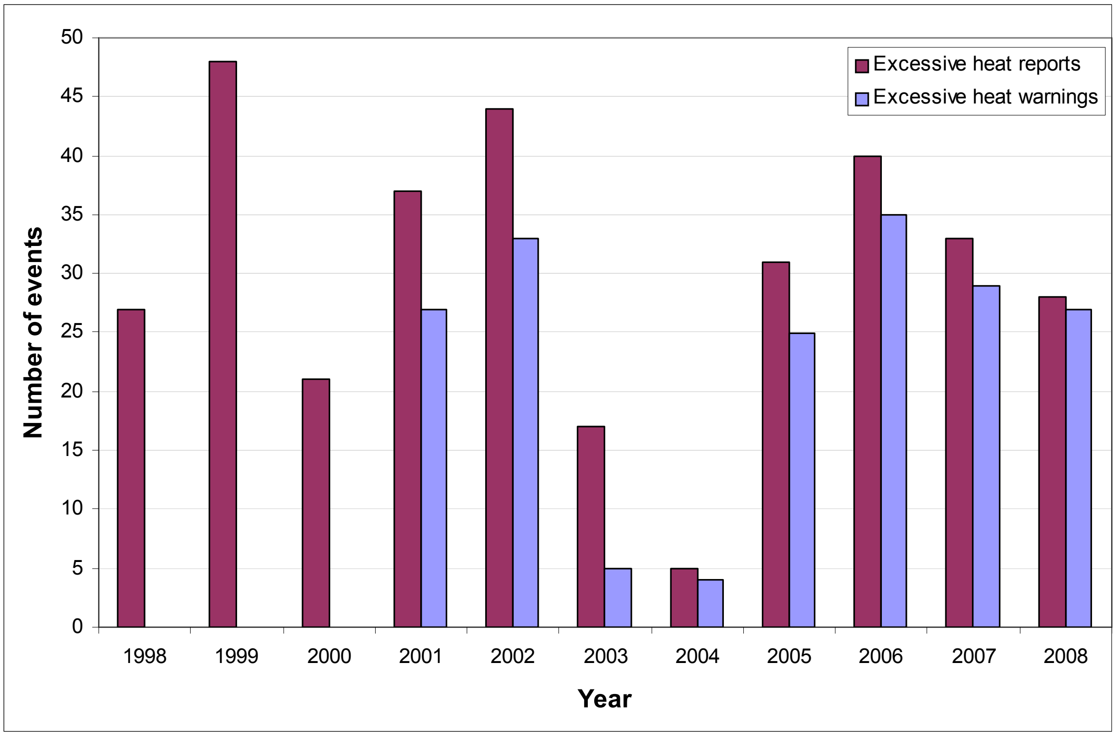
HEAT WAVES

There is no universally accepted definition of a heat wave in the climate change literature. Meehl and Tebakdi used two quantitative measures based on the duration and/or intensity of either nighttime minimum or daytime maximum temperatures [13]. We chose a more qualitative approach and determined that a heat wave occurs when a minimum of three consecutive excessive heat reports are generated from National Weather Service (NWS) stations for the same location. We also noted when an excessive heat warning was issued as a measure of severity [60]. We opted to use a more qualitative approach since people in the affected areas will still require emergency services, even if the duration or severity of the incident does not meet a particular quantitative threshold.

Historical incidence

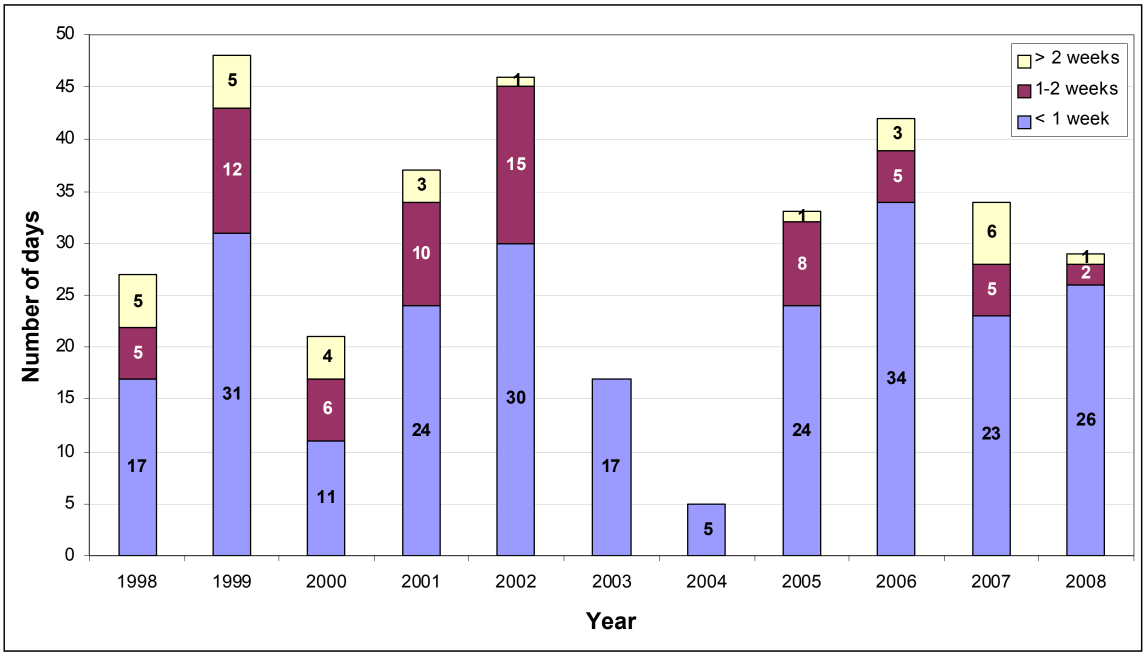
A summary of the number of excessive heat reports is shown from 1998 through 2008 in Figure 11 [61]. A total of 339 excessive heat reports were issued across the U.S. from 1998 through 2008, which is shown by the pink line. We can use as a measure of severity whether an excessive heat warning was issued by NWS [62], which is shown as the blue line in Figure 13. In most, but not all, cases, if an excessive heat warning was issued, there was a corresponding excessive heat report.

Figure 11. Excessive heat reports and NWS excessive heat warnings, 1998-2008



We can also look at the duration of the heat waves from 1998 through 2008 as a measure of severity. Based on the excessive heat reports, there were 242 heat waves that lasted one week or less (71 percent of the total), 68 that lasted between 1 and 2 weeks (20 percent of the total), and 29 that lasted more than 2 weeks (9 percent of the total). Figure 12 shows a yearly breakdown of the total number of heat waves from 1998 through 2008, with the blue portion representing those heat waves that lasted less than 1 week, the red portion representing those that lasted between 1 and 2 weeks, and the yellow portion representing those that lasted more than 2 weeks.

Figure 12. Heat wave duration, 1998-2008



Role of emergency management

The Philadelphia region is often impacted by heat waves, and therefore provides a good case study to examine the roles and responsibilities for local and State emergency management agencies. From 1998 through 2008, the Philadelphia region experienced 24 heat waves, for an average of about two each year. The average length of each heat wave was 5.4 days, with the longest lasting 15 days (in July/August 1999).

The Philadelphia Hot Weather–Health Watch/Warning System (PWWS) is a model that was developed in 1995 to predict when excessive heat presents a high risk to human health. Based on the PWWS forecasts, the local NWS office then determines whether to issue a warning [63,64]. When the NWS issues a warning, city agencies and other private organizations activate a series of activities [63,64]:

- Television and radio stations and newspapers are asked to publicize the oppressive weather conditions, along with information on how to avoid heat-related illnesses.
- Media announcements also suggest that friends, relatives, neighbors, and other volunteers activate their "buddy system" to visit elderly persons regularly during excessive heat events. The "buddies" are asked to make sure that susceptible individuals have food and water, fans and working ventilation, and other amenities to manage the excessive heat.
- The Philadelphia Corporation for the Aging operates a "heat-line" to provide information to the public on heat stress and the avoidance of heat-related injuries. The media is asked to publicize the heat-line telephone number, and a large display is raised that can be seen over much of the center of Philadelphia. During a relatively short but intense heat wave in July 1999, the heat-line recorded over 700 calls. The Philadelphia Corporation for the Aging also distributes fans.
- The Department of Public Health contacts nursing homes and persons requiring extra care to provide information and offer advice on the protection of residents. During a heat wave in Au-

gust of 2002, they also required group homes to keep room temperatures below 81 degrees. They can also move susceptible persons out of dangerous living situations and into air-conditioned shelters.

- The utility company and water department halt service suspensions.
- The Fire Department Emergency Medical Service increases staffing in anticipation of increased service demand.
- The Philadelphia Office of Supportive Housing activates increased outreach activities to assist the homeless and contracts with Project Home, a private outreach program that provides water and support to the city's homeless.
- Senior centers extend their hours of operation of air-conditioned facilities.

In addition, record-setting water and electricity usage is not uncommon during heat waves in the Philadelphia region. For example, during a 3-day heat wave in July 1999 the strain on electrical systems caused about 20,000 homes and businesses to lose power. The record for water usage was also exceeded during that heat wave [65].

Finally, excessive heat also impacts the transportation sector. For example, during the July 1999 heat wave, the Pennsylvania Department of Transportation reported that 15 roadways buckled and several had to be closed. During a heat wave in August 2001, Interstate 95 buckled near Philadelphia International Airport, Southeastern Pennsylvania Transportation Authority regional rail lines operated with delays due to downed wires, and several trains and buses overheated [66].

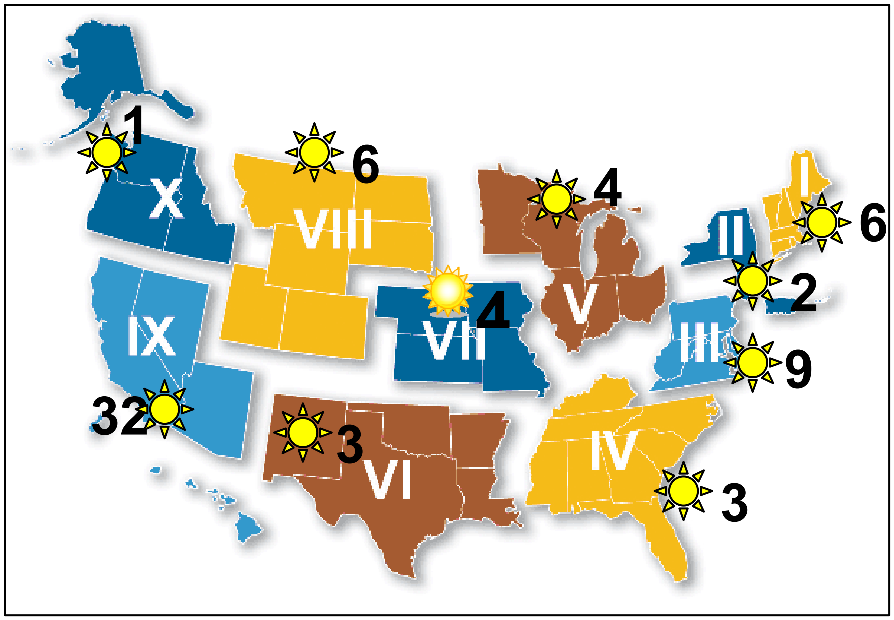
Impact of climate change

It is generally accepted in the climate change literature that the U.S. average temperature has risen more than 2°F over the past 50 years. Further, the literature suggests that by the end of the 21st century, the average U.S. temperature could increase by 7 to 11°F using a higher emissions scenario and by 4 to 6.5°F using a lower emissions scenario [8]. An increase in average temperature is likely to produce more frequent and intense heat waves [67]. However, this is not necessarily an indicator of future instances of more intense heat waves; nor does it provide any information about which areas will be more susceptible to heat waves in the future.

FEMA Regions III, IV, V, VI, VII, and IX have experienced the most heat waves over the last 10 years, as shown in Figure 13. According to the climate change literature, these regions are most likely to see an increase in heat wave severity. For example, modeling by Meehl and Tebaldi examined how the increase in global mean temperatures will affect the weather patterns that produce heat waves. The results from the model predict a greater increase in heat wave severity in the Western, Midwestern, and Southeastern U.S. [13], which is also consistent with research highlighted in the *Global Climate Change Impacts in the United States* report [8]. Further, additional research indicates that those areas that typically experience heat waves are likely to face more severe, longer heat waves in the future [67]. While these regions may be more accustomed to heat waves, more severe and/or frequent heat waves will further tax local emergency management, public health, and social services.

The Meehl and Tebaldi model also indicates that the Pacific Northwest could also experience an increase in the number, duration, and intensity of heat waves in the future [13]. This is significant since the Pacific Northwest region has not traditionally experienced many heat waves and may not be as prepared as the other regions to manage the response.

Figure 13. Heat waves across the U.S., 1998-2008 [61]



FOODBORNE AND WATERBORNE DISEASES

We are including foodborne and waterborne diseases in this review even though they do not fall directly under the purview of emergency management agencies. There are tens of thousands of reports of foodborne and waterborne diseases each year, and the climate change models predict that the number of cases will increase in the future [8,14,15]. Further, given the highly visible nature of an outbreak, the resulting public concern, and the possibility of involving several Federal, State, and local agencies, it seems likely that emergency management agencies at the Federal and State jurisdictions will have a role in coordinating the response to the large and/or multi-State outbreaks.

For the purposes of this report, we are only interested in those reports that are classified as waterborne disease outbreaks (WBDOs) and foodborne disease outbreaks (FBDO). An event must meet two criteria to be defined as a WBDO by the Centers for Disease Control and Prevention (CDC):

1. Two or more persons must be epidemiologically linked by the location of the exposure, time, and characteristics of the illness.
2. The epidemiologic evidence must show clear evidence that the water source (water for recreational purposes, drinking water, water not intended for drinking, or water of unknown intent) is responsible for the illness [68].

In addition, the CDC defines an FBDO as the occurrence of two or more cases of a similar illness resulting from the ingestion of the same type of food [69]. For our purposes, we were only interested in those FBDOs that affected multiple States, since those events would be most likely to trigger involvement of State and/or Federal emergency management agencies.

Historic trends

Between 1998 and 2006, there were a total of 72 multi-State FBDOs affecting more than 6,300 people. The median number of people affected per FBDO over that time period was 43. The largest outbreak occurred in 2002, sickened 510 people, and was traced to salmonella in tomatoes. The most common disease causing pathogens over that time include E.Coli, Salmonella, Hepatitis A, Listeria, and Vibrio [70].

A more detailed breakdown of the number of FBDOs and number of people affected during that time period is shown in Table 3. Between 1997 and 2006, a total of 199 WBDOs affected more than 13,000 people. In that timeframe, the median number of people affected per WBDO was 12. However, there were 22 instances where more than 100 people were sickened and two instances where more than 1,000 people were affected. The largest outbreak occurred in New York in 2005, affected 2,307 people from a fountain in a State park that was found to be contaminated with Cryptosporidium. In most of these instances, the WBDO did not extend to multiple States. The common disease causing pathogens included Cryptosporidium, Giardia, and Legionella [71].

A more detailed breakdown of the number of WBDOs and the number of people affected during that time period is shown in Table 4.

Table 3. Multi-State FBDOs and number of people affected, 1998-2008

Year	Multi-State FBDOs	People affected
1998	7	970
1999	8	611
2000	9	872
2001	4	125
2002	6	758
2003	10	349
2004	8	980
2005	12	562
2006	8	1077

Table 4. WBDOs and number of people affected, 1997-2008

Year	WBDOs	People affected
1997	7	568
1998	19	1936
1999	14	1072
2000	28	1661
2001	13	736
2002	21	1230
2003	14	1011
2004	24	821
2005	26	3473
2006	33	737

It is important to note that these data represent only those cases reported to the CDC. It is therefore likely that there were additional cases and/or outbreaks that were not treated by a medical practitioner, unrecognized by a primary care or emergency room physician, and/or not tested for a waterborne or foodborne pathogen [72,73].

Role of emergency management

We include foodborne and waterborne diseases in this report, even though emergency management agencies are typically not directly involved in the response. Most WBDOs and FBDOs are identified and investigated by State and local public health departments. The cryptosporidium outbreak in Milwaukee in 1993 that sickened an estimated 400,000 people provides a useful example. In April 1993, epidemiologists with the Milwaukee Department of Health identified a trend of widespread absenteeism among hospital employees, students, and schoolteachers due to gastrointestinal illness. Upon laboratory confirmation of cryptosporidium oocysts, the Milwaukee Department of Health coordinated with State and local officials to identify the source of the outbreak and provide guidance to affected citizens [74]

At the Federal level, the CDC can provide assistance, upon request, especially for those outbreaks that are sufficiently widespread and/or severe. In addition, State, local, and territorial public health departments voluntarily report data on WBDOs and FBDOs on an annual basis to the CDC Enteric Diseases Epidemiology Branch. The CDC also maintains several disease surveillance and outbreak detection systems. For example, PulseNet is a national surveillance network consisting of the CDC, State, and local public health laboratories and Federal food regulatory agency laboratories. The CDC uses OutbreakNet to collaborate with State, local, and territorial public health partners once a potential outbreak is identified. The CDC also coordinates with local, State, and Federal regulatory agencies such as the Food and Drug Administration and the U.S. Department of Agriculture Food Safety and Inspection Service [75].

Sufficiently large and/or significant outbreaks also have the potential to involve additional agencies within the Department of Homeland Security (DHS), including the U.S. Customs and Border Protection and Office of Health Affairs. Such was the case during the 2007 melamine contamination of pet food and animal feed [76]. Given the possibility of large and widespread outbreaks that involve multiple Federal agencies, as well as agencies from several States, it is likely that DHS will be continue to be asked to coordinate the Federal response in the future.

Impact of climate change

In 2001, Rose et al concluded that the incidence of foodborne and waterborne diseases is linked to precipitation and temperature; much of the data and evidence for this conclusion was preliminary at the time [15]. Since then, several studies have corroborated Rose's paper, and it was used as the basis for the Intergovernmental Panel on Climate Change reports, as well as several other recent non-profit and government reports [8]. For example, Kistemann et al. concluded that the concentrations of Giardia and Cryptosporidium in waterways and drinking water reservoirs increase significantly after rainfall and extreme runoff events [77]. Casmen et al developed incidence diagrams to depict the impact of climate change on cryptosporidiosis. They concluded that the expected consequences of climate change could increase the frequency of WBDOs, but the impact will be lessened in more developed countries that invest in a comprehensive public health sector [78]. Further, D'Souza et al. examined the relationship of ambient temperature and reports of salmonella in five Australian cities. They observed a statistical correlation between rising temperatures and reports of salmonella the following month [79].

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