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FUTURE EXTREME HEAT CONSIDERATIONS FOR EMERGENCY MANAGERS

by

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September 2024

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13. ABSTRACT (maximum 200 words)

Extreme heat poses a significant and growing threat to emergency management and homeland security within the United States, yet many communities remain unprepared for their impacts due to inadequate planning. This thesis explores the potential future impact of extreme heat on America's emergency management community. The study specifically focuses on future extreme heat effects in Phoenix, Chicago, Seattle, and Atlanta, representing a diverse cross-section of climates in the United States. The study employs a scenario-based approach for each city to determine the shocks of extreme heat events in future global temperature increases of +1.5ºC, +2.0ºC, and +2.5ºC above pre-industrial levels. Each scenario focuses on the expected effects on Federal Emergency Management Agency (FEMA) Community Lifelines, representing vital functions of a community to ensure safety, security, and well-being. The thesis underscores the importance of planning for extreme heat specifically and the cascading effects of extreme heat on communities and infrastructure. Recommendations to mitigate the growing challenge of extreme heat events on communities include creating plans specific to the hazard, preparing for cascading impacts, focusing on heat awareness and communications, and advocating funding for communities to address extreme heat threats.

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FUTURE EXTREME HEAT CONSIDERATIONS FOR EMERGENCY MANAGERS

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ABSTRACT

Extreme heat poses a significant and growing threat to emergency management and homeland security within the United States, yet many communities remain unprepared for their impacts due to inadequate planning. This thesis explores the potential future impact of extreme heat on America's emergency management community. The study specifically focuses on future extreme heat effects in Phoenix, Chicago, Seattle, and Atlanta, representing a diverse cross-section of climates in the United States. The study employs a scenario-based approach for each city to determine the shocks of extreme heat events in future global temperature increases of +1.5ºC, +2.0ºC, and +2.5ºC above pre-industrial levels. Each scenario focuses on the expected effects on Federal Emergency Management Agency (FEMA) Community Lifelines, representing vital functions of a community to ensure safety, security, and well-being. The thesis underscores the importance of planning for extreme heat specifically and the cascading effects of extreme heat on communities and infrastructure. Recommendations to mitigate the growing challenge of extreme heat events on communities include creating plans specific to the hazard, preparing for cascading impacts, focusing on heat awareness and communications, and advocating funding for communities to address extreme heat threats.

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LIST OF ACRONYMS AND ABBREVIATIONS

CDC	Centers for Disease Control and Prevention
COVID-19	coronavirus disease 2019
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
IPCC	International Panel on Climate Change
NWS	National Weather Service

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EXECUTIVE SUMMARY

Extreme heat is a major U.S. homeland security threat that will increase in the coming years. The Centers for Disease Control and Prevention (CDC) attribute an average of 1,220 deaths to extreme heat yearly, with preliminary fatality numbers from 2023 and 2024 being significantly higher.[1] Climate change and demographic trends will increase the threat of extreme heat in the future, with one study suggesting "heat-related mortality is projected to be more than double by the 2050s" compared to current levels.[2] In the wake of this increasing threat, many emergency managers and communities are not adequately prepared.[3] However, preparing for extreme heat and its potentially cascading impact in many parts of the country is overlooked as other risks dominate long-term planning within emergency management agencies. Formulating solutions to this complex problem is challenging, but recognizing extreme heat concerns and threats within the emergency management community will facilitate better planning and mitigation when extreme heat events occur.

This thesis analyzes the potential shocks of extreme heat on America's emergency management community in the future. Specifically, the thesis focuses on future extreme

[1] "Extreme Heat and Your Health," Extreme Heat, accessed September 22, 2023, https://www.cdc.gov/disasters/extremeheat/heat_guide.html; "AP Analysis Finds 2023 Set Record for U.S. Heat Deaths, Killing in Areas That Used to Handle the Heat," AP News, May 31, 2024, https://apnews.com/article/record-heat-deadly-climate-change-humidity-south-11de21a526e1cbe7e306c47c2f12438d; and Zahra Hirji and Preeti Soni, "No One Knows Exactly How Many People Are Dying from Extreme Heat," Bloomberg, July 8, 2024, https://www.bloomberg.com/news/features/2024-07-08/how-many-people-have-died-from-extreme-heat-officials-struggle-to-track.

[2] Cunrui Huang et al., "Projecting Future Heat-Related Mortality under Climate Change Scenarios: A Systematic Review," *Environmental Health Perspectives* 119, no. 12 (December 2011): 1683, https://doi.org/10.1289/ehp.1103456.

[3] Nicole A. Errett et al., "Survey of Extreme Heat Public Health Preparedness Plans and Response Activities in the Most Populous Jurisdictions in the United States," *BMC Public Health* 23, no. 1 (2023): 9, https://doi.org/10.1186/s12889-023-15757-x; C. J. Gabbe et al., "Why and How Do Cities Plan for Extreme Heat?," *Journal of Planning Education and Research*, 2021, 11, https://doi.org/10.1177/0739456X211053654; Brian Stone, Jr. et al., "Compound Climate and Infrastructure Events: How Electrical Grid Failure Alters Heat Wave Risk," *Environmental Science & Technology* 55, no. 10 (2021): 6963, https://doi.org/10.1021/acs.est.1c00024; and Nicholas Kimutis, Tamara Wall, and Lyndsey Darrow, "Emergency Management Short Term Response to Extreme Heat in the 25 Most Populated U.S. Cities," *International Journal of Disaster Risk Reduction* 100 (2024): 1–9, https://doi.org/10.1016/j.ijdrr.2023.104097.

heat impacts in Phoenix, Chicago, Seattle, and Atlanta. These cities represent a diverse cross-section of U.S. climates and, therefore, represent a much larger number of urban areas. The study employs a scenario-based approach for each city to determine the effects of extreme heat events in future global temperature increases of +1.5ºC, +2.0ºC, and +2.5ºC above pre-industrial levels. Research demonstrates that the frequency and severity of extreme heat events directly correlate with broader global temperature change scenarios used in this thesis.[4] Thus, an increase in extreme heat events will directly correlate with future global temperature increases.

Each warming scenario focuses on the expected impacts on Federal Emergency Management Agency (FEMA) Community Lifelines, representing vital functions of a community to ensure safety, security, and well-being. FEMA's Community Lifelines correlate to a community's response and recovery priorities after a natural disaster. Each "lifeline" represents a critical sector crucial to a community's recovery, including:[5]

1. Safety and security
2. Food, hydration, and shelter
3. Health and medical
4. Energy (power and fuel)
5. Communications
6. Transportation
7. Hazardous materials
8. Water systems

This thesis uses scenario planning to identify and evaluate the potential ramifications of future extreme heat events within a community based on FEMA Community Lifelines.

[4] Alessandro Dosio et al., "Extreme Heat Waves under 1.5 °C and 2 °C Global Warming," *Environmental Research Letters* 13, no. 5 (May 2018): 1–10, https://doi.org/10.1088/1748-9326/aab827.

[5] Federal Emergency Management Agency, "Community Lifelines," Federal Emergency Management Agency, accessed October 24, 2023, https://www.fema.gov/emergency-managers/practitioners/lifelines.

The analysis showed that all four cities included in the scenarios would likely see an increasing number of extreme heat events in the future, paired with an increase in event severity in future climates. This increase will be felt more strongly in temperate cities across the northern tier of the U.S., where a combination of fewer mitigation measures (such as air conditioning) and lower acclimatization to hot temperatures paired with a more significant rate of change in frequency of extreme heat events will have the greatest impact on communities and, therefore, emergency managers. Negative public health consequences will remain the greatest threat from extreme heat events, and they will grow in all three climate scenarios of +1.5ºC, +2.0ºC, and +2.5ºC.

The scenarios showed that while some planning is individualized depending on each community, communities must plan for cascading events related to extreme heat. The two most important considerations during an extreme heat event will be maintaining electrical power and water service. While maintaining these two lifelines may seem like common sense, almost every other critical sector will also see massive disruption if these two sectors fail. The failure could also lead to a large loss of life during an extreme heat event, renewing the discussion about protecting our critical infrastructure and the need for closer collaboration between the utility industry and emergency management staff in planning efforts.

Based on the extreme heat scenarios and comparative analysis, the recommendations for emergency managers to consider when preparing for future extreme heat events include preparing for cascading impacts, creating heat-specific plans, focusing on all sectors instead of just public health, improving heat awareness and communication, and advocating for enhanced funding for extreme heat threats to address future concerns.

One of the primary findings in this thesis is the widespread risk of cascading events occurring during extreme heat events. These cascading events can range from power grid failures due to the overuse of electricity, to water shortages, to the greater potential for subsequent flooding events in the Midwest in the wake of heat episodes. Extreme heat is a deadly natural disaster, but it has the potential to be deadly at a much higher magnitude if other critical support systems fail. Extreme heat preparation and planning must focus on low-risk/high-impact events, which will become the high-risk/high-impact events of the future.

While emergency management planning efforts have improved over the years, much of the effort has gone into producing "All Hazards" plans. These plans are meant to reduce the need to create a separate document for different hazards or emergencies. One critique of this process is that it rarely includes the necessary detail to respond to an extreme heat event. Many All Hazards plans neglect to plan for cascading impacts, especially since extreme heat is a hazard rarely localized to a single community. These plans should include private-sector utilities and healthcare networks, water-consuming sectors such as irrigation districts, and disadvantaged communities that are sometimes neglected in community engagement processes.

Public health is still at the forefront of the extreme heat discussion, as many of the negative consequences that are experienced in these events are directly related to public health outcomes. This suggests that short-term planning and mitigation should still be focused on the health sector. In practice, this focus could look like increased outreach to vulnerable populations, such as those with cardiovascular or respiratory diseases, as well as socially isolated individuals who may not have transportation to travel to a cooling center. While the health sector is vital, it is also important not to put all the focus on a single sector while ignoring other critical sectors that could have an equally large impact on a community should they be negatively affected.

Almost every extreme heat death is preventable, yet a combination of factors continues to lead to deaths every year. One recommendation is to incorporate universal standards to warn about extreme heat events in an easy-to-understand way. The recommendation also focuses on urging people-first messaging to reduce the use of scientific jargon and focus on the action an individual should take. Communication requires a trusted messenger to relay the information. The messenger could be a trusted advocate in a socially vulnerable community or a doctor for someone with a condition that makes them more vulnerable to heat. Although these campaigns are currently in place for some jurisdictions, many communities at most significant risk from deadly extreme heat events do not have public awareness campaigns.

Emergency managers must also rely on elected officials and official budgets for additional funding to support these initiatives, yet public officials often prioritize more pressing needs instead of funding for additional support during extreme heat events. Emergency managers must continue to improve extreme heat awareness with elected officials to ensure the officials are aware of more frequent and impactful future events and the potential for more staff and resources.

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I. INTRODUCTION

Extreme heat is a major U.S. homeland security threat that will increase in the coming years, and many emergency managers and communities are not adequately prepared.[1] Although less noticeable in media coverage compared to other natural disasters, extreme heat is a ubiquitous problem worsened by warming global temperatures, expanding drought, and changing weather patterns caused by climate change.[2] An Environmental Protection Agency (EPA) report indicates that heat waves are becoming more intense and frequent, with the largest municipalities in the U.S. seeing a threefold increase in heat waves since the 1960s.[3] Extreme heat events will increasingly tax emergency managers and communities, requiring novel solutions and refined planning and mitigation techniques to deal with the threat.

To be sure, the most significant impact of extreme heat overall is on public health. Extreme heat has caused more deaths in the United States than any other natural disaster.[4] The Centers for Disease Control and Prevention (CDC) attributes an average of 1,220 deaths to extreme heat yearly.[5] High levels of fatalities directly or indirectly related to extreme heat happen for many reasons, ranging from cardiovascular and pulmonary conditions to dehydration.[6] To highlight this threat, Alejandro Mayorkas, the Department of Homeland Security Secretary, stated, "Extreme Heat, worsened by the climate crisis,

[1] Errett et al., "Survey of Extreme Heat Public Health Preparedness," 9; Gabbe et al., "Why and How Do Cities Plan for Extreme Heat?," 11; Stone, Jr. et al., "Compound Climate and Infrastructure Events," 6963; Kimutis, Wall, and Darrow, "Emergency Management Short Term Response," 1–9.

[2] Molly Taft, "The Media Has No Idea How to Cover Extreme Heat," *New Republic*, July 14, 2023, https://newrepublic.com/post/174301/media-no-idea-cover-extreme-heat; The summer of 2023 has widely been described as the hottest summer since global records began in 1880, according to NASA. Climate scientist Paulo Ceppi suggested July 2023 may have seen the hottest daily temperature on Earth in at least 125,000 years, according to a recent Washington Post article.

[3] "Climate Change Indicators: Heat Waves," Climate Change Indicators, accessed September 22, 2023, https://www.epa.gov/climate-indicators/climate-change-indicators-heat-waves.

[4] Environmental Protection Agency.

[5] "Extreme Heat and Your Health."

[6] Environmental Protection Agency, "Climate Change Indicators."

threatens the lives, safety, and security of communities everywhere."[7] Extreme heat is a problem for communities and will, therefore, become a problem for emergency managers, which the future will amplify.

Climate change and demographic trends will increase the threat of extreme heat in the future. Seth Borstein of the Associated Press notes that "between 1970 and 2000, the United States averaged about 2.3 billion person-days of extreme heat each year. But between 2040 and 2070, that number will be between 10 and 14 billion person-days a year," a sixfold increase in prevalence according to research conducted by the National Center for Atmospheric Research and City University of New York.[8] This spike is simultaneously co-occurring as populations become more vulnerable to heat. With the population aging and migrating to states in the southern tier of the country that are most prone to extreme heat, or "Sun Belt" states, the risk affects this target population.[9] Kenny et al. warn that "individuals over the age of 60 years are consistently the most vulnerable" to extreme heat, with "82 to 92 percent of excess mortality occurring in this group."[10] About 50 percent of the nation lives in the Sun Belt, which will likely increase to about 55 percent by 2030.[11] This area relies on air conditioners and commonly suffers power disruptions, making

[7] "Department of Homeland Security Offers Community Leaders New Resources to Prepare for Extreme Temperature Events as 17 States Experience Record Breaking Heat," Department of Homeland Security Press Releases, August 24, 2023, https://www.dhs.gov/news/2023/08/24/department-homeland-security-offers-community-leaders-new-resources-prepare-extreme.

[8] Andrew C. Revkin, "Study Finds Sun Belt Population Growth and Warming Climate Could Quadruple Exposure to Extreme Heat," *Dot Earth* (blog), May 18, 2015, https://archive.nytimes.com/dotearth.blogs.nytimes.com/2015/05/18/study-finds-sun-belt-population-growth-and-warming-climate-could-quadruple-exposure-to-extreme-heat/.

[9] Laura Suarez-Gutierrez et al., "Hotspots of Extreme Heat under Global Warming," *Climate Dynamics* 55, no. 3–4 (August 2020): 437, https://doi.org/10.1007/s00382-020-05263-w.

[10] Glen P. Kenny et al., "Heat Stress in Older Individuals and Patients with Common Chronic Diseases," *CMAJ : Canadian Medical Association Journal* 182, no. 10 (July 13, 2010): 1053, https://doi.org/10.1503/cmaj.081050.

[11] Tim Wang and Julie Laumont, "The Rise of the U.S. Sun Belt," Clarion Partners, April 1, 2019, https://www.clarionpartners.com:443/insights/sun-belt-apartments-multifamily.

residents more vulnerable to heat-related hazards.[12] The aging population in these states most prone to extreme heat events compounds this vulnerability. One study suggests that "heat-related mortality is projected to be more than double by the 2050s" compared to current levels.[13] This development indicates that the burden on healthcare professionals, first responders, and emergency management staff will multiply drastically.

Yet despite these concerns, the sense of urgency about the threat to emergency managers is mixed, as many other hazards dominate planning efforts. In many parts of the country, preparing for extreme heat and its potentially cascading impact is overlooked as other risks dominate long-term planning within emergency management agencies. The lack of planning is most common in places with consistently high temperatures but a lack of distinct extreme heat events, such as in the southeastern U.S.[14] A 2023 Duke University study suggests that "the significance of extreme heat is often understated in state Hazard Mitigation plans," with "only 25 states having a section dedicated to extreme heat."[15] Thus, half of U.S. states do not have a solid plan for explicitly dealing with extreme heat events, leaving them significantly unprepared. Formulating solutions to this complex problem is challenging, but recognizing extreme heat concerns and threats within the emergency management community will facilitate better planning and mitigation when extreme heat events occur.

A. RESEARCH QUESTION

What are the potential future impacts of extreme heat on America's emergency management community?

[12] Kyusik Kim et al., "A Comparative Assessment of Cooling Center Preparedness across Twenty-Five U.S. Cities," *International Journal of Environmental Research and Public Health* 18, no. 9 (2021): 1–2, https://doi.org/10.3390/ijerph18094801; Bridget R. Kane et al., *Defending the United States against Critical Infrastructure Attacks: Exploring a Hypothetical Campaign of Cascading Impacts* (Santa Monica, CA: RAND Corporation, 2024), 6–7, https://www.rand.org/pubs/research_reports/RRA2397-3.html.

[13] Huang et al., "Projecting Future Heat-Related Mortality," 1683.

[14] Jordan Clark and Ashley Ward, *Defining Extreme Heat as a Hazard: A Review of Current State Hazard Mitigation Plans* (Durham, NC: Duke University, Nicholas Institute for Energy, Environment & Sustainability, 2023), 6, https://hdl.handle.net/10161/27339.

[15] Clark and Ward, 5.

B. LITERATURE REVIEW

The literature review evaluates research on the topic of extreme heat, with specific emphasis on expected global temperature increases in the future. This proposal focuses on three, high-level categories of relevant literature: the expected magnitude of global temperature increases compared to a pre-industrial average, the impact of extreme heat events on public health and mortality, and the role of emergency managers during extreme heat events.

The first category summarizes existing research, establishing the expected magnitude of these increases to inform the following scenarios. Peer-reviewed research often hypothesizes short- and long-term temperature rises. However, due to several factors associated with climate change, these values have been debated and have potentially high margins of error. In this context, scientists see the International Panel on Climate Change (IPCC) as the gold standard for climate warming projections, and the organization produces highly credible reports reflecting a global perspective on expected future climate conditions.[16] The IPCC has predicted between 1.5ºC and 2.5ºC increase in temperatures by 2050 and an even higher increase in temperature increases and temperature uncertainty beyond that date.[17] The IPCC also takes a more conservative view on temperature change projections. From the Paris Agreement, even the most conservative climate projection indicates that 1.5ºC of warming is nearly a certainty, even if the peak of greenhouse gas emissions is decreasing by 2025 and falling 43 percent by 2030.[18] Therefore, the 1.5ºC warming threshold informs the most conservative scenario in the thesis.

Other peer-reviewed literature outlines more significant uncertainty on future global temperatures because of climate feedback mechanisms and current temperatures well above published projections. For example, one recently published article shows global

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[16] Intergovernmental Panel on Climate Change, *Climate Change 2023: Synthesis Report* (Geneva, Switzerland: Intergovernmental Panel on Climate Change, 2023), https://doi.org/10.59327/IPCC/AR6-9789291691647.

[17] Intergovernmental Panel on Climate Change, 17.

[18] "The Paris Agreement," United Nations Climate Change, accessed October 24, 2023, https://unfccc.int/process-and-meetings/the-paris-agreement.

temperatures already exceeded the 1.5ºC threshold on 38 days in 2023 as of mid-September.[19] Although the daily average temperature significantly differs from the yearly average, this data demonstrates the uncertainty of approaching unknown climate tipping points that can substantially change these projections.

All available peer-reviewed research reviewed concurs that global warming is occurring.[20] This debate is outside the scope of the thesis. The central question concerns the extent of such warming. Several articles and reports published by Ripple et al. indicate that the rate of warming has accelerated in 2023, which could lead to more frequent and severe extreme heat events soon.[21]

A second subset of research focuses on the impacts of extreme heat on public health, given the high mortality rates during extreme heat events. Public health is perhaps the most prominent when discussing extreme heat, with extensive literature published in the past several years. Such discussions of heat-related mortality separate the average population and an elderly or infirm population. For example, Huang et al. evaluate the relationship between climate change and heat-related mortality and offer insights into potential future impacts on public health.[22] The study found that "significant differences in projected mortality can be found in different [greenhouse gas] emissions scenarios."[23]

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19 William J. Ripple et al., "The 2023 State of the Climate Report: Entering Uncharted Territory," *BioScience*, 2023, 1, https://doi.org/10.1093/biosci/biad080.

20 Intergovernmental Panel on Climate Change, *IPCC, 2023*; Ripple et al., "The 2023 State of the Climate Report"; William J. Ripple et al., "World Scientists' Warning of a Climate Emergency 2021," *BioScience* 71, no. 9 (September 2021): 894–98, https://doi.org/10.1093/biosci/biab079; William J. Ripple et al., "Many Risky Feedback Loops Amplify the Need for Climate Action," *One Earth* 6, no. 2 (February 17, 2023): 86–91, https://doi.org/10.1016/j.oneear.2023.01.004; Daniel J. Vecellio et al., "Greatly Enhanced Risk to Humans as a Consequence of Empirically Determined Lower Moist Heat Stress Tolerance," *Proceedings of the National Academy of Sciences* 120, no. 42 (2023): 1–9, https://doi.org/10.1073/pnas.2305427120; James E. Hansen et al., "Global Warming in the Pipeline," *Oxford Open Climate Change* 3, no. 1 (2023): 1–33, https://doi.org/10.1093/oxfclm/kgad008; Dosio et al., "Extreme Heat Waves under 1.5 °C and 2 °C Global Warming"; and Robin D. Lamboll et al., "Assessing the Size and Uncertainty of Remaining Carbon Budgets," *Nature Climate Change* 13 (October 2023): 1360–67, https://doi.org/10.1038/s41558-023-01848-5.

21 Ripple et al., "Many Risky Feedback Loops"; Ripple et al., "The 2023 State of the Climate Report."

22 Huang et al., "Projecting Future Heat-Related Mortality."

23 Huang et al., 1688.

Vecellio et al. published a paper extrapolating these mortality impacts to 4ºC.[24] This paper also showed specific rises in extreme heat duration for Chicago and New York City based on several temperature scenarios, all indicating more significant impacts in future extreme heat events.[25] Thus, extreme heat seems strongly correlated with mortality for the elderly and sick, and specific temperatures have differential impacts.

Some research concludes that extreme heat may affect the disadvantaged even more than the elderly. Almost all of the research indicates that older individuals suffer more significant heat impacts than the general population, such as research from Belmin et al. and Jay et al.[26] However, one body of research argues that "disadvantaged communities" may be more vulnerable to extreme heat.[27] This disadvantage is likely partially due to inequities in living conditions and the relative lack of air conditioning in those communities.[28] Overall, the research agrees that health-related risk factors from extreme heat are similar globally.

Meta trends will also increase these threats. For example, population migration and demographic change will increase the likelihood of heat-related mortality as individuals with higher health risk factors move into geographies with higher extreme heat risk. Revkin and Clarion discuss the increased possibility and prevalence of impacts due to excessive heat in these contexts.[29] An additional body of research focuses on the increasing

[24] Vecellio et al., "Greatly Enhanced Risk to Humans."

[25] Vecellio et al., 4–5.

[26] Joël Belmin et al., "Level of Dependency: A Simple Marker Associated with Mortality during the 2003 Heatwave among French Dependent Elderly People Living in the Community or in Institutions," *Age and Ageing* 36, no. 3 (2007): 298–303, https://doi.org/10.1093/ageing/afm026; Ollie Jay et al., "Reducing the Health Effects of Hot Weather and Heat Extremes: From Personal Cooling Strategies to Green Cities," *Lancet* 398 (August 21, 2021): 720, https://doi.org/10.1016/S0140-6736(21)01209-5.

[27] According to the USDA, disadvantaged communities generally have fewer socioeconomic resources and thus less capacity to adapt to the challenges of climate change. Many of these disadvantages are associated with environmental racism and systemic oppression. Economically disadvantaged individuals tend to experience the highest rates of poor overall health, reduced mobility, reduced access to health care, and economic limitations that affect access to goods and services that can help with the negative effects of climate change. These individuals face more exposure to heatwaves and poor air quality and have less access to evacuation measures (e.g., cars and reliable public transportation).

[28] Jay et al., "Reducing the Health Effects of Hot Weather," 709.

[29] Revkin, "Study Finds Sun Belt Population Growth"; Wang and Laumont, "The Rise of the U.S. Sun Belt."

frequency of extreme heat in developing countries. Suarez-Gutierrez et al., Chak et al., and Vahmani et al. conclude that the most significant and impactful changes in excessive heat frequency and vulnerability appear outside of the United States.[30] Vecellio et al. suggest that these impacts are unfolding in some parts of the world and that extreme heat duration—and therefore impact—will increase exponentially under future warming scenarios.[31] This thesis focuses on the United States; however, equatorial regions outside of the United States are on the front lines of the crisis of extreme heat and are already seeing acute impacts.

Although specific mitigation measures underway in various countries worldwide may help emergency managers in the United States, many factors, such as location, impact, and culture, make comparisons difficult. Therefore, decision-makers must critically evaluate research from other counties before drawing too many conclusions. For example, the Belmin et al. case study from the 2003 heatwave in France and a similar event in London studied by Mitchell et al. can inform U.S. thinking, even though direct comparisons are difficult.[32] Since a considerable body of knowledge exists on climate and extreme heat impacts on American cities, this research prioritizes them.

A final subset of research highlights the roles of the emergency management community in dealing with extreme heat threats before, during, and after those events occur. Clark and Ward show the level of preparedness of state emergency management agencies and where gaps in preparedness currently lie.[33] They show that approximately one-half of states do not have a plan to address extreme heat. Likewise, Errett et al. conducted a similar study showing even more significant gaps in big city "Heat Action

[30] Suarez-Gutierrez et al., "Hotspots of Extreme Heat under Global Warming"; Ho Hung Chak et al., "Mortality Risk of a Future Heat Event across a Subtropical City: Implications for Community Planning and Health Policy," *Natural Hazards* 103, no. 1 (2020): 623–37, https://doi.org/10.1007/s11069-020-04003-x; and P. Vahmani, Andrew D. Jones, and Christina M. Patricola, "Interacting Implications of Climate Change, Population Dynamics, and Urban Heat Mitigation for Future Exposure to Heat Extremes," *Environmental Research Letters* 14, no. 8 (2019): 1–10, https://doi.org/10.1088/1748-9326/ab28b0.

[31] Vecellio et al., "Greatly Enhanced Risk to Humans," 6.

[32] Belmin et al., "Level of Dependency"; Daniel Mitchell et al., "Attributing Human Mortality during Extreme Heat Waves to Anthropogenic Climate Change," *Environmental Research Letters* 11, no. 7 (2016): 1, https://doi.org/10.1088/1748-9326/11/7/074006.

[33] Clark and Ward, *Defining Extreme Heat as a Hazard*.

Plans."[34] These unique perspectives are a few bodies of research attempting to quantify the need for additional planning around extreme heat mitigation and expanding outreach and communication about current plans.[35] Naughton et al. also emphasize the importance of local planning by showing how Chicago's Extreme Weather Operation Plans, created after a deadly 1995 heat wave, may have resulted in fewer deaths during an extreme heat event in 1999 due to a higher level of community support to vulnerable individuals.[36] This Chicago example shows how creating a specific plan to address extreme heat event vulnerabilities yields tangible benefits.

Extreme heat is a hazard that rarely only affects a single vulnerability within a jurisdiction, with cascading impacts being common. Some studies even discuss compounding disasters, such as power failures during extreme heat events in cities such as Atlanta and Phoenix, which would undoubtedly involve emergency managers.[37] The Stone et al. thesis shows an overall lack of preparedness in these compounding events, demonstrating that few cities with cooling centers could accommodate the expected influx of residents needing this type of infrastructure.[38] Specific research exploring these second- and third-order effects after critical infrastructure failure during extreme heat events represents a gap; this thesis explores additional direct and indirect impacts further as research continues.

C. RESEARCH DESIGN

The research design employs a scenarios-based study to define the impacts of extreme heat events on emergency managers in various warming scenarios. Different peer-reviewed studies, governmental research reports, and scientific literature informed the research. The uncertain nature of the extent of future warming suggests the incorporation

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[34] Errett et al., "Survey of Extreme Heat Public Health Preparedness," 9.

[35] Errett et al., 9.

[36] Mary P. Naughton et al., "Heat-Related Mortality during a 1999 Heat Wave in Chicago," *American Journal of Preventive Medicine* 22, no. 4 (2002): 227, https://doi.org/10.1016/S0749-3797(02)00421-X.

[37] Stone, Jr. et al., "Compound Climate and Infrastructure Events," 8.

[38] Stone, Jr. et al., 9.

of a scenario-based framework to extrapolate second- and third-order effects affecting emergency managers.

Scenario planning originated with the concept of war-gaming. It gained popularity in the private sector when it was used by Pierre Wack to correctly postulate that a crisis scenario could cause oil prices to spike before the 1973 oil crisis occurred, bringing a significant competitive and financial advantage for the Shell Corporation.[39] Scenario planning is a valuable tool to plan for future conditions across various disciplines. According to Fahey, future, scenario-based case studies improve “scenarios foster [ing] preparedness” by allowing practitioners to “anticipate a range of potential futures and get ready for them before they occur.”[40] In addition, Augier et al. find that scenario-based planning is “ideally suited” for climate adaptation planning, and public and private sector organizations commonly use it to deal with such problems.[41] Therefore, this thesis proposes three distinct scenarios linked to expected global temperature rises.

A scenario-based research design is essential in this context since several contrasting projections relate to how much above pre-industrial temperature levels warming will occur. However, this research is temperature-bound rather than time-bound. The warming could happen in 2 or 200 years, but the impacts will likely be similar, absent significant technological advances. These scenarios used benchmarks of +1.5ºC, +2.0ºC, and +2.5ºC of warming. A +1.5°C and +2.5°C scenario were included based on conservative and aggressive warming predictions by around 2050.[42] Two degrees Celsius is the agreed-upon limit in warming noted in the Paris Climate Accords and the middling scenario in this thesis.[43] Although global warming and extreme heat events differ in this

[39] Kees Van der Heijden, *Scenarios: The Art of Strategic Conversation*, 2nd ed. (West Sussex, UK: John Wiley & Sons, 2006).

[40] Liam Fahey, “How Corporations Learn from Scenarios,” *Strategy & Leadership* 31, no. 2 (2003): 8, https://doi.org/10.1108/10878570310698070.

[41] Mie Augier et al., “Organizational Persistence in the Use of War Gaming and Scenario Planning,” *Long Range Planning* 51, no. 4 (August 2018): 10, https://doi.org/10.1016/j.lrp.2017.12.005.

[42] David Herring, “Climate Change: Global Temperature Projections,” Understanding Climate, March 6, 2012, http://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature-projections.

[43] United Nations Climate Change, “The Paris Agreement.”

study, research definitively shows that extreme heat events correlate with broader global temperature changes.[44] The increased prevalence of extreme heat events correlated with warming helped define the rationale for the three scenarios introduced in the thesis. More significantly, all three scenarios are plausible outcomes for emergency managers just entering the workforce.

Much of the previous research benchmarks warming at degree or half-degree intervals, which this thesis adopts, instead of extrapolating and introducing unnecessary uncertainty into an already hazy arena. However, most emergency management communities focus on short- to medium-term impacts because of workload and competing priorities. Therefore, this thesis focused on relevant scenarios within current emergency managers' lifetimes (and careers). With the global temperature anomalies in 2023 and 2024, previously unknown tipping points within the climate system could propel temperatures faster than expected or predicted. Therefore, interrelated and cascading impacts have been explored in each scenario.

Each of the four scenario cities were selected for a specific reason. First, they are all major cities with large populations that will experience the greatest human impact. They are all distinct from one another in climate. Phoenix has a dry, hot, desert climate with historical water shortages, whereas Atlanta has a hot, humid climate that may see an expanding number of extreme heat events due to the combination of heat and humidity. Conversely, Chicago has a temperate climate but is occasionally prone to extreme heat in the summer. The population of Chicago is not acclimated to heat events in the same way as many southern cities. Therefore, the emergency management community in Chicago could see differing impacts within this scenario. Seattle, located along the Pacific coast, represents a mild climate where extreme heat events are rare, yet significant. Although these cities provide a generalized scenario for each temperature metric, they also will represent broader swaths of the United States, as shown in Köppen-Geiger Climate Classifications maps.[45] Figure 1 shows climate classification maps for the United States,

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[44] Dosio et al., "Extreme Heat Waves under 1.5 °C and 2 °C Global Warming."

[45] Markus Kottek et al., "World Map of the Köppen-Geiger Climate Classification Updated," *Meteorologische Zeitschrift* 15, no. 3 (2006): 259–63, https://doi.org/10.1127/0941-2948/2006/0130.

showing areas with similar climates. Using Köppen-Geiger Climate Classifications, the impacts on these four scenario cities can be extrapolated to include reasonable extreme heat scenarios for larger parts of the country.[46] In Figure 1, these four scenarios encapsulate four distinct climate zones that together make up much of the U.S. land area, as well as much of the population.

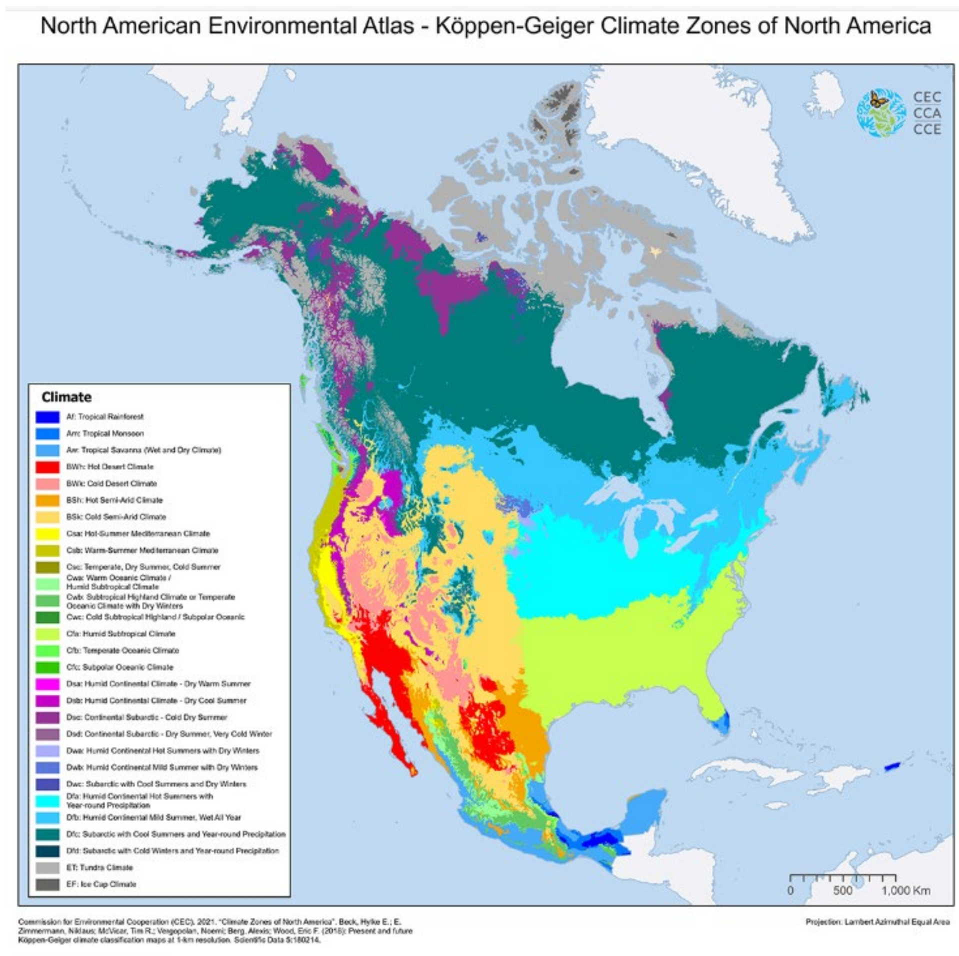

Figure 1. Climate Zones Map Showing the Distribution of Climate Types across North America Based on the Köppen-Geiger Climate Classification[47]

[46] Kottek et al.

[47] Source: Hylke E. Beck et al., “Present and Future Köppen-Geiger Climate Classification Maps at 1-Km Resolution,” *Sci Data* 5 (2018): 1–12, https://doi.org/10.1038/sdata.2018.214.

The report includes implications for emergency managers based on preparing and mitigating these potential impacts in each scenario by corresponding to future planning efforts surrounding FEMA community lifelines.[48] The FEMA community lifelines correlate to many emergency managers' response and recovery priorities and can apply to response and recovery from extreme heat events. Each "lifeline" represents a critical sector that is crucial to the recovery of a community hit by a disaster.

The thesis also explores the impact of increasingly frequent extreme heat events on emergency managers when such disasters limit the capability for mutual aid and outside resources to assist. Ultimately, the goal is to raise awareness of the current and future threats associated with extreme heat and to develop specific recommendations and conclusions for emergency managers to apply across disparate geographies in a warmer climate of the future. This increased awareness will hopefully lead to additional extreme heat planning efforts for locations without a current plan and an emphasis on including cascading scenarios within those planning efforts.

48 "Community Lifelines."

II. BACKGROUND ON THE THREAT OF EXTREME HEAT

This chapter provides scenario background about the threat of extreme heat, including the distinction between extreme heat and global warming, an overview of historical and future temperature trends, and the connection between extreme heat events and the emergency management community. This chapter also prefaces the four extreme heat scenarios discussed in subsequent chapters. It also outlines the FEMA community lifeline framework for analyzing the critical impacts of extreme heat on communities. This analysis will set the stage for the concept of extreme heat and explain some of the complex nuances to consider when entering the discussion.

A. EXTREME HEAT VS. GLOBAL WARMING

The difference between global warming and extreme heat is critical to understand as it clarifies that the definition of extreme heat is open to debate among scientists and citizens alike. "Global warming" describes the overall long-term warming seen globally since pre-industrial times on a global scale and is part of the underlying climate.[49] On the other hand, "extreme heat" is defined at the event level and is more open to personal and geographical interpretation. FEMA defines extreme heat as "a long period (2 to 3 days) of high heat and humidity with temperatures above 90 degrees" in most areas.[50] By this definition, a city such as Atlanta sees extreme heat for several months out of a given summer. By the same token, a consistently hot Phoenix may not technically reach the definition due to the dry desert climate.

Many major cities have instituted their own definitions of extreme heat. For example, response thresholds for extreme heat in San Francisco start at 80–85ºF, while Austin, Texas, must expect a heat index to reach 108ºF.[51] This wide discrepancy leads to confusion about the overall threat that extreme heat poses and highlights the geographical

[49] "What Is Climate Change?," Climate Change: Vital Signs of the Planet, accessed February 24, 2024, https://climate.nasa.gov/what-is-climate-change.

[50] "Extreme Heat," FEMA Preparedness Community, accessed February 24, 2024, https://community.fema.gov/ProtectiveActions/s/article/Extreme-Heat.

[51] Kimutis, Wall, and Darrow, "Emergency Management Short Term Response," 7.

variation of temperature and heat index thresholds that define extreme heat. For example, 49 percent of National Weather Service (NWS) offices have created their own criteria for issuing heat-related weather advisories and warnings, as seen in Figure 2.[52]

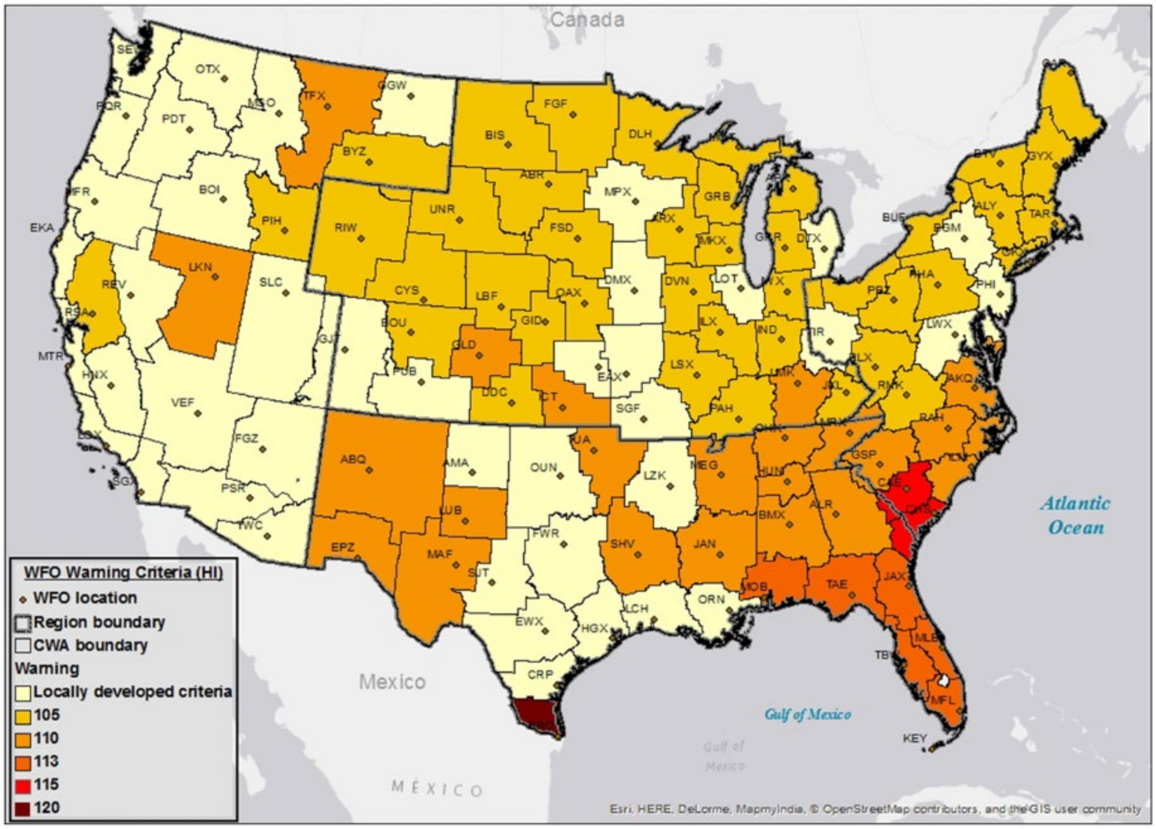

Figure 2. Heat Index Values that Trigger the Issuance of an Extreme Heat Warning by the Local National Weather Service Office[53]

Based on Figure 2, the differences in heat advisory criteria vary significantly depending on locality. Nearly half of the National Weather Service offices use “locally developed criteria,” which are not obvious to the average consumer of weather alerts. To the general public who are not versed in the definition of extreme heat, or do not know the

[52] Michelle D. Hawkins, Vankita Brown, and Jannie Ferrell, “Assessment of NOAA National Weather Service Methods to Warn for Extreme Heat Events,” *Weather, Climate, and Society* 9, no. 1 (2017): 7–8, https://doi.org/10.1175/WCAS-D-15-0037.1.

[53] Source: Hawkins, Brown, and Ferrell, 10.

exact boundaries of the local National Weather Service office, these criteria may add to confusion about what “extreme heat” actually means.

This confusion is further exacerbated by different tools showing conflicting levels of risk to the general public. Figure 3 shows the graphic of post on the social media network X from the National Integrated Heat Health Information System. The map shows National Weather Service advisories and warnings overlayed on top of an experimental “HeatRisk” map, showing the highest risk for negative health outcomes. Figure 3 demonstrates the disparities between these two products; some locations with “extreme” heat risk are not covered by any warnings or advisories, while other locations with lower “HeatRisk” values see active advisories from the National Weather Service. These disparities act to confuse the public further and add to the uncertainty of which personal protective measures should be taken in an extreme heat event.

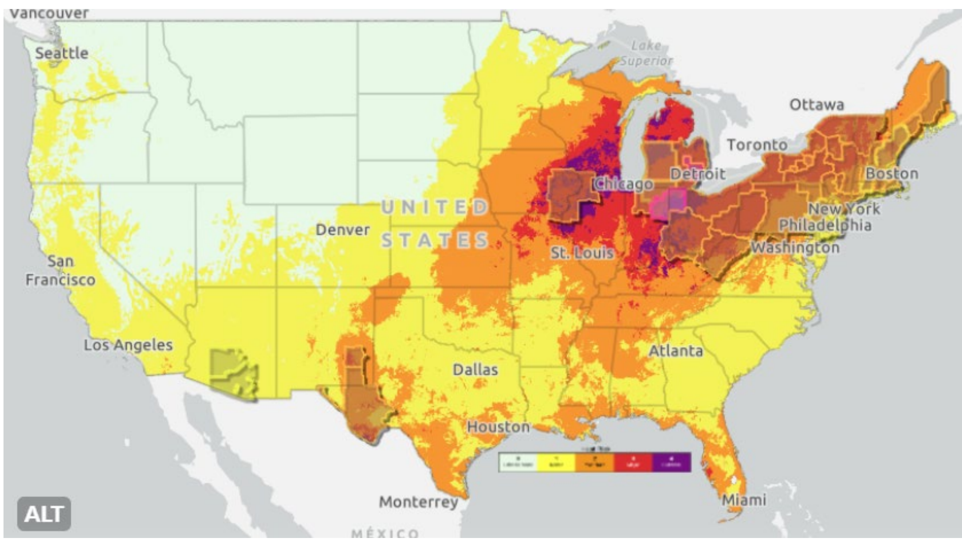

Figure 3. Graphic of National Weather Service Heat Watches and Warnings and the Agency’s Experimental “HeatRisk” Product on June 18, 2024[54]

[54] Source: National Integrated Heat Health Information System [@HeatGov], “#Heat Is Impacting Areas across the Country, Particularly in the Midwest and Northeast, with More than 76 Million People Currently under Heat Alerts. Visit Http://Heat.Gov for Information about How Heat Is Impacting Your Area and Steps You Can Take to Stay Safe. Https://T.Co/7MPC0qipS2,” Tweet, *Twitter*, June 18, 2024, https://x.com/HeatGov/status/1803102550595371122. Purple values demonstrate “extreme” ‘Heat Risk’ values.

This thesis uses the following definition for "extreme heat": an anomalous combination of heat and humidity that require(s) a significant interdisciplinary response to mitigate the effects on the population at a local level. The author created this definition to highlight extreme heat effects on the population and infrastructure of a specific geographic area that is unusual for that area.

Extreme heat events can directly correlate with overall global temperature change as heat events become more frequent and impactful as global temperatures rise. According to one study, a warming of +1.5ºC would cause 13.8 percent of the world's population to experience at least one extreme heat event every 5 years.[55] Most regions globally will experience 7.5 times more heatwaves in a +1.5ºC climate as compared to a pre-industrial climate.[56] A +1.5ºC hotter climate is not a distant threat. The World Meteorological Association suggests it is likely that the globe will temporarily exceed +1.5ºC within the next five years.[57] This time frame leaves emergency managers little time for planning efforts as temperatures continue to warm and extreme heat events become more frequent.

In an environment with the warming of +2.0ºC, the number of extreme heat exposures jumps to 36.9 percent, representing nearly a threefold increase in exposure to extreme temperatures.[58] Other studies suggest this risk increases exponentially as global temperatures continue to climb.[59] Since extreme heat population exposure increases in a parabolic fashion, in the absence of intervention, extreme heat consequences will follow the same pattern.

A compounding factor includes the increase in atmospheric moisture with increasing temperatures. This increase in moisture leads to higher heat indices and

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55 Dosio et al., "Extreme Heat Waves under 1.5 °C and 2 °C Global Warming," 1.

56 S. E. Perkins-Kirkpatrick and P. B. Gibson, "Changes in Regional Heatwave Characteristics as a Function of Increasing Global Temperature," *Scientific Reports* 7, no. 1 (2017): 7, https://doi.org/10.1038/s41598-017-12520-2.

57 "Global Temperature Is Likely to Exceed 1.5°C above Pre-Industrial Level Temporarily in next 5 Years," World Meteorological Organization, June 4, 2024, https://wmo.int/news/media-centre/global-temperature-likely-exceed-15degc-above-pre-industrial-level-temporarily-next-5-years.

58 Dosio et al., "Extreme Heat Waves under 1.5 °C and 2 °C Global Warming," 1.

59 Vecellio et al., "Greatly Enhanced Risk to Humans," 3.

increased heat stress on populations.[60] Scientists often refer to the "wet-bulb temperature" when discussing extreme heat impacts on humans. The "wet-bulb temperature" is defined by considering the air temperature and the amount of moisture within the air—among other environmental factors—and is used as an indicator of how efficiently the body can cool itself.[61] This metric can more effectively measure heat stress on an individual, which also directly correlates with negative health outcomes.

Scientists generally agree on a theoretical limit to the body's ability to cool itself. Vecellio et al. suggest that a wet-bulb temperature of 35ºC (approximately 95ºF) is the maximum threshold where the average person can regulate body temperature.[62] Li et al. show this figure to be approximately 33ºC.[63] However, this maximum threshold assumes a healthy individual and will vary for each individual based on age, comorbidities, and socioeconomic factors. Many heat-related fatalities occur below this threshold.[64] When a person is exposed to an environment with a higher wet bulb temperature, the body temperature rises and eventually causes hyperthermia.

Although extreme heat can imperil people's lives, the wet bulb threshold remains unsettled in the literature. According to the Cleveland Clinic, hyperthermia occurs when a body absorbs more heat than it can release.[65] This phenomenon increases body temperatures and heat illnesses, such as heat stroke. In extreme cases, untreated hyperthermia can lead to death.[66] Extreme heat events have frequently caused deaths at much lower wet bulb temperatures, such as the 1995 Chicago heatwave, where the wet

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[60] George Luber and Michael McGeehin, "Climate Change and Extreme Heat Events," *American Journal of Preventive Medicine* 35, no. 5 (2008): 430, https://doi.org/10.1016/j.amepre.2008.08.021.

[61] Dawei Li, Jiacan Yuan, and Robert E. Kopp, "Escalating Global Exposure to Compound Heat-Humidity Extremes with Warming," *Environmental Research Letters* 15, no. 6 (May 2020): 1–2, https://doi.org/10.1088/1748-9326/ab7d04.

[62] Vecellio et al., "Greatly Enhanced Risk to Humans," 2.

[63] Li, Yuan, and Kopp, "Escalating Global Exposure," 5.

[64] Li, Yuan, and Kopp, 4.

[65] "Hyperthermia: Symptoms, Causes, Treatment and Recovery," Cleveland Clinic, accessed February 24, 2024, https://my.clevelandclinic.org/health/diseases/22111-hyperthermia.

[66] Cleveland Clinic.

bulb temperature averaged 31ºC.[67] The significant wet-bulb threshold is highly variable and is based on geography, social factors, and heat mitigation strategies. However, this threshold is currently poorly understood and can vary due to other causes. This uncertainty adds a layer of complexity for emergency management planners when trying to identify a critical threshold when an increased number of heat-related illnesses and deaths may occur.

The wet bulb temperature will be an even larger focus on human health outcomes in warmer climates. Studies have shown that extremely high wet-bulb temperatures will rapidly increase in the future, with an outsized impact on human health and mortality.[68] This change is partially due to the increased ability of air to hold moisture as the temperature increases. The laws of thermodynamics roughly state that for an increase in temperature by one degree Celsius, the amount of water vapor in the atmosphere increases by 7 percent.[69] This increase in moisture adds to the apparent temperature, making it more difficult for the body to cool itself.[70] This increase in atmospheric moisture has impacts beyond public health, although emergency management during the event must examine acute effects.

Emergency managers must consider the effects of cascading weather events immediately following extreme heat. The increase in the amount of moisture typically present during extreme heat events can cause compounded events of extreme heat followed by extreme flooding in some parts of the country, such as the Midwest.[71] This phenomenon results in a seemingly topsy-turvy reality where extreme heat leads to extreme rainfall and

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[67] Li, Yuan, and Kopp, "Escalating Global Exposure," 5.

[68] Ethan D. Coffel, Radley M. Horton, and Alex de Sherbinin, "Temperature and Humidity Based Projections of a Rapid Rise in Global Heat Stress Exposure during the 21st Century," *Environmental Research Letters* 13, no. 1 (2018): 7, https://doi.org/10.1088/1748-9326/aaa00e.

[69] Alan Buis, "Steamy Relationships: How Atmospheric Water Vapor Amplifies Earth's Greenhouse Effect," Ask NASA Climate, February 8, 2022, https://climate.nasa.gov/explore/ask-nasa-climate/3143/steamy-relationships-how-atmospheric-water-vapor-amplifies-earths-greenhouse-effect/.

[70] Vecellio et al., "Greatly Enhanced Risk to Humans," 1.

[71] Wei Zhang and Gabriele Villarini, "Deadly Compound Heat Stress-Flooding Hazard across the Central United States," *Geophysical Research Letters* 47, no. 15 (2020): 6, https://doi.org/10.1029/2020GL089185.

flooding, further demonstrating the cascading effects of extreme heat events on an emergency manager.

In drier climates, extreme heat can increase wildfires and the subsequent impact of wildfire smoke across large areas.[72] Widespread wildfire smoke was seen across a large swath of the United States in 2023 after Canadian wildfires, which high temperatures partially fueled.[73] One study suggested that climate change made the 2022 wildfires in Argentina and Uruguay 60 times more likely, leading to widespread power outages in the area. These compounding disasters could include not only a larger public health threat but also a larger impact on public infrastructure and economic activity.[74] These compounding impacts keep emergency managers up at night, yet the planning process often neglects them entirely.

B. HISTORICAL TEMPERATURE FLUCTUATIONS

Global temperatures have been fluctuating for millennia. Before the Industrial Revolution, the drivers of global temperature change were primarily particulates from volcanic eruptions, solar activity, and other natural climate variability, such as fluctuating ocean temperatures.[75] The invention of fossil fuel–driven technology in the 18th century introduced carbon dioxide as another driver in temperature change, along with the increase in other greenhouse gas–producing byproducts of industrialization. This thesis does not address the current and future causes driving global temperature change but rather the effects of changing temperatures and the direct correlation between overall global temperature increases and extreme heat risk.

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[72] Noam Rosenthal et al., "Population Co-Exposure to Extreme Heat and Wildfire Smoke Pollution in California during 2020," *Environmental Research: Climate* 1, no. 2 (August 2022): 2, https://doi.org/10.1088/2752-5295/ac860e.

[73] Ripple et al., "The 2023 State of the Climate Report," 6.

[74] Zhang and Villarini, "Deadly Compound Heat Stress-Flooding Hazard," 6.

[75] Ed Hawkins et al., "Estimating Changes in Global Temperature since the Preindustrial Period," *Bulletin of the American Meteorological Society* 98, no. 9 (September 2017): 1842–43, https://doi.org/10.1175/BAMS-D-16-0007.1.

Global temperatures are generally compared to the baseline known as "pre-industrial," meaning the average mean global temperature before the influence of combustion engines. Some scientists disagree about what a global temperature "baseline" looks like, given natural temperature fluctuations occurring during this time.[76] However, the International Panel on Climate Change generally uses the timeframe of approximately 1850 through 1900, although negligible temperature increases may have started occurring before.[77] Therefore, the scenarios within this thesis adopt the same timeframe suggested as "pre-industrial" by the International Panel on Climate Change.

The International Panel on Climate Change suggests a high confidence that "global surface temperature has increased faster since 1970 than in any other 50-year period over the last 2000 years."[78] In 2023, the IPCC suggested that the best estimate of total, human-caused temperature increase between the pre-industrial benchmark and the 2010–2019 time period was +1.07ºC.[79] The present global temperature shows that the three scenarios of +1.5ºC, +2.0ºC, and +2.5ºC are realistic outcomes for the emergency management community to plan for.

The +1.5ºC scenario represents a relatively short-term scenario. Recent news articles indicate that 2023 already averaged +1.5ºC compared to pre-industrial averages worldwide.[80] Although one single year does not indicate a trend, some studies suggest that feedback loops and "tipping points" happened earlier than expected, which will further lead to uncertainty of future global temperatures.[81] Due to this uncertainty, this thesis concentrates on the impact of extreme heat events as they relate to average global temperatures rather than focusing on when those impacts will take place. The uncertainty

[76] Andrew P. Schurer et al., "Importance of the Pre-Industrial Baseline in Determining the Likelihood of Exceeding the Paris Limits," *Nature Climate Change* 7, no. 8 (August 2017): 563–67, https://doi.org/10.1038/nclimate3345.

[77] Hawkins et al., "Estimating Changes in Global Temperature," 1849.

[78] Intergovernmental Panel on Climate Change, *IPCC, 2023*, 4.

[79] Intergovernmental Panel on Climate Change, 4.

[80] Umair Irfan, "2023 Was the Hottest Year on Record. It Also Pushed the World over a Dangerous Line," Vox, February 8, 2024, https://www.vox.com/23969523/climate-change-cop28-paris-1-5-c-uae-2023-record-warm.

[81] Ripple et al., "The 2023 State of the Climate Report," 1.

also demonstrates a greater need for contingency planning associated with extreme heat events for multiple plausible warming trajectories and outcomes.

C. FUTURE PROJECTIONS

The extent to which global temperatures will continue to increase largely depends on future carbon emission scenarios. Scientific bodies have significant discussions regarding which warming scenarios are most plausible. The IPCC uses scenarios based on one-half-degree increments from 1.5º to 2.5ºC and one-degree increments at 3º and 4ºC.[82] Many other scholarly articles also describe warming scenarios and impacts in similar intervals.[83] The prevalence of these intervals is a primary reason for pegging the warming thresholds described in this thesis to these temperatures for the purposes of scenario planning.

Researchers widely disagree about how quickly the world will reach these temperature benchmarks. The Intergovernmental Panel on Climate Change projections indicate between +1.5ºC and +2.5ºC of warming by 2050 and between +1.5ºC and +5ºC by 2100.[84] Figure 4 shows the uncertainty of future global temperature trends in the medium- to long-term according to the IPCC and how future climate highly depends on future greenhouse gas emissions. Figure 4 also demonstrates one of the primary reasons that this thesis will focus on temperature thresholds rather than time-based scenarios. Although the extreme variability of these scenarios may not seem particularly helpful for long-term planners within the emergency management community, scholars concur on the strong chance that global temperatures and increases in the frequency of extreme heat events will necessitate additional planning and mitigation in the future. Impacts correlated

[82] Intergovernmental Panel on Climate Change, *IPCC, 2023*, 10.

[83] Allison Crimmins, "The 5th National Climate Assessment in 15 Maps," National Climate Assessment Interactive Atlas, December 1, 2023, https://storymaps.arcgis.com/stories/0c8f2a21bd8d438fb4503e13cee8c682; Dosio et al., "Extreme Heat Waves under 1.5 °C and 2 °C Global Warming"; and Carl-Friedrich Schleussner et al., "1.5°C Hotspots: Climate Hazards, Vulnerabilities, and Impacts," *Annual Review of Environment and Resources* 43, no. 1 (2018): 135–63, https://doi.org/10.1146/annurev-environ-102017-025835.

[84] Intergovernmental Panel on Climate Change, *IPCC, 2023*, 17.

with overall global changes to the climate will drive the extent of these planning and mitigation measures.

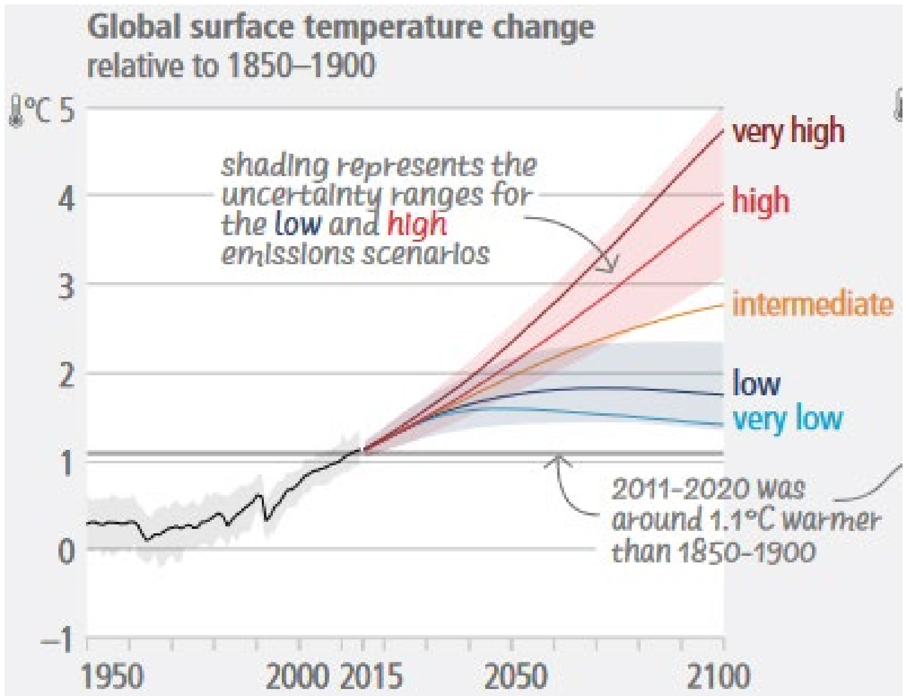

Figure 4. Projected Average Global Temperature Increases Compared to Pre-Industrial Averages Based on Emission Scenarios[85]

Despite the uncertainty expressed in Figure 4 beyond 2050, the thesis scenarios focus on the "intermediate" emissions scenario. This prediction generally would place the +1.5ºC temperature change in 2030, the +2.0ºC temperature change in 2050, and the +2.5ºC temperature change in 2090. Although these estimates may be considerably off later in the century, this scenario provides a reasonable, middling emissions estimate in which to discuss long-range climate impacts that will affect extreme heat.

One must understand that the thresholds discussed in previous paragraphs use global temperature averages. Regional variations in warming are present, with the largest

[85] Source: Intergovernmental Panel on Climate Change, 17.

impacts being in the polar latitudes.[86] While North America shows localized warming exceeding the global climate average, Figure 5 illustrates the significant variations forecast for each region of the United States. The figure shows that the greatest degree of warming targets the northern half of the country, with some areas already approaching or exceeding +2.0ºC. Accelerated warming is significant because extreme heat probability and impact directly correlate to larger warming trends.

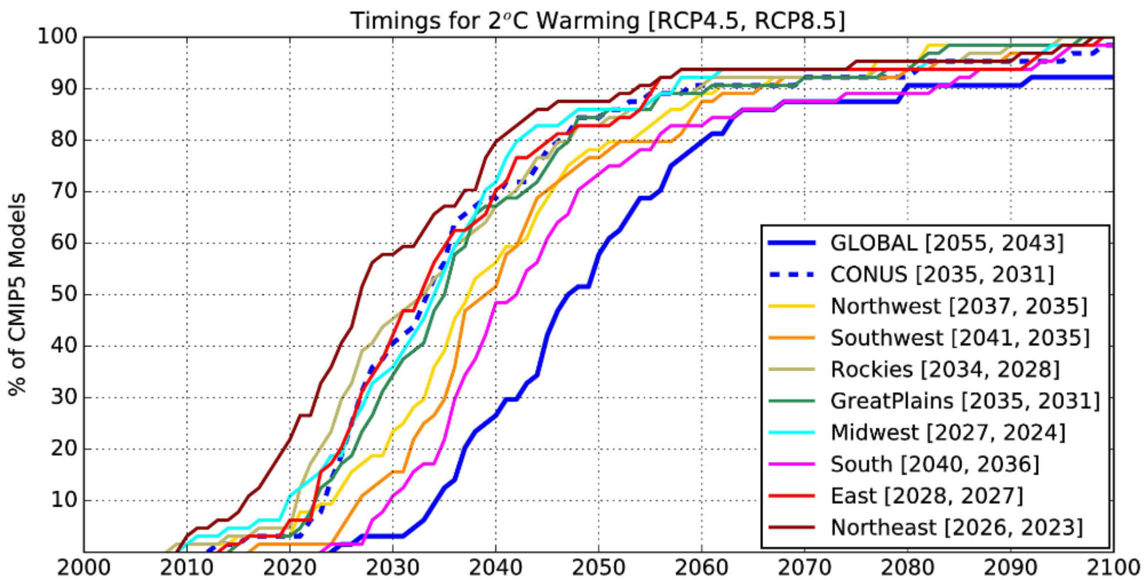

Figure 5. Regional Comparison between Crossing the 2ºC Threshold Based on Lower and Higher Emissions Scenarios[87]

These accelerated warming trends are also more common over land, which will obviously have a greater impact on the emergency management community. Seneviratne et al. suggest that global warming of +2.0ºC may equate to 2 to 3ºC of warming across the

[86] Perkins-Kirkpatrick and Gibson, "Changes in Regional Heatwave Characteristics," 1–10; Sonia I. Seneviratne et al., "Allowable CO2 Emissions Based on Regional and Impact-Related Climate Targets," *Nature* 529, no. 7587 (January 28, 2016): 478, https://doi.org/10.1038/nature16542.

[87] Source: Ambarish V. Karmalkar and Raymond S. Bradley, "Consequences of Global Warming of 1.5 °C and 2 °C for Regional Temperature and Precipitation Changes in the Contiguous United States," ed. Juan A. Añel, *PLOS ONE* 12, no. 1 (January 11, 2017): 8, https://doi.org/10.1371/journal.pone.0168697. The bracketed years to the right of each region indicate the expected year that each region would cross +2.0ºC based on 64 projections.

continental United States and 3 to 5ºC of warming in Alaska.[88] This difference shows that extreme heat events may be even more common in certain parts of the world, including the United States, in the future.

D. EMERGENCY MANAGEMENT AND CLIMATE CHANGE

The emergency management profession reacts to natural and man-made threats on a local, regional, and national scale. However, as climate change accelerates, these professionals will face an increase in the frequency and severity of natural disasters. Federal Emergency Management Agency Director Deanne Criswell said, "the threat landscape is changing. We are seeing direct impacts of climate change on the severe weather events we are experiencing. We no longer have disaster seasons. We are busy year-round."[89] The expected increase in future emergency management requirements will require a corresponding increase in the building and sustaining of emergency management capacity and capabilities. Since different geographies will have different impacts from the hazard of extreme heat events, the future emergency management requirements derived from extreme heat risks will vary by geography.

Although the emergency management profession is rarely considered a "first responder," emergency managers are often called upon when local first responders are overwhelmed. This reliance certainly happened during other public health emergencies such as the COVID-19 pandemic. Therefore, the threat of extreme heat will increasingly become an emergency management concern when local first responders become overwhelmed. However, the effects of extreme heat on the emergency management community are not solely limited to public health. Cascading and compounding impacts will affect other critical infrastructure and services within the community, as many are reliant on one another to function. These second-order impacts are often less obvious and less anticipated in the planning process.

[88] Seneviratne et al., "Allowable CO2 Emissions," 479.

[89] "FEMA Administrator Deanne Criswell's Remarks on the U.S. Approach to Crisis Management," Federal Emergency Management Agency, May 3, 2022, https://www.fema.gov/fact-sheet/fema-administrator-deanne-criswells-remarks-us-approach-crisis-management.

Figure 6 shows a systems map illustrating the interdependencies and cascading impacts of climate change in general across several societal domains, including infrastructure, human health, and community. The map demonstrates the complex nature of interdependencies seen when discussing climate change impacts such as extreme heat. Although some of these loops are well-defined and predictable, others are unpredictable and prone to cascading impacts that affect other systems. This unexpected feedback will increasingly become more common as temperatures rise and runaway impacts of climate change manifest themselves in ways not currently anticipated.

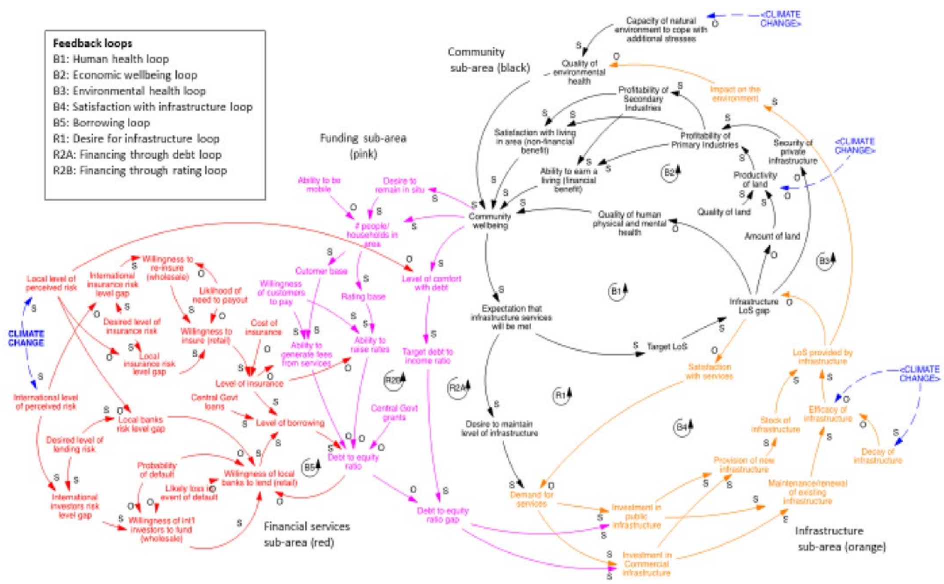

Figure 6. Systems Map of Impacts to Multiple Domains from Climate Change, Showing the Complex Interdependencies between Elements[90]

Despite the uncertain future that a changing climate will bring, professionals can anticipate some certainties in the emergency management space when discussing response and recovery from natural disasters, including extreme heat. Emergency managers know the importance of critical infrastructure and crucial commodities required for community recovery after an event. One way that FEMA can identify disaster-related impacts on

90 Source: Judy Lawrence, Paula Blackett, and Nicholas A. Cradock-Henry, "Cascading Climate Change Impacts and Implications," *Climate Risk Management* 29 (2020): 5, https://doi.org/10.1016/j.crm.2020.100234.

society is by using the community lifelines concept. FEMA community lifelines were introduced in the aftermath of Hurricane Maria to make more informed assessments of the state of response and recovery objectives associated with restoring vital services to Puerto Rico. FEMA's community lifelines include "the most fundamental services of a community that, when stabilized, enable all other aspects of society to function."[91] These community lifelines include health and medical services, transportation, communications, energy, and other vital components of a fully functioning society.[92] Figure 7 shows a visual depiction of the eight community lifelines, as well as a list of components found in each lifeline.

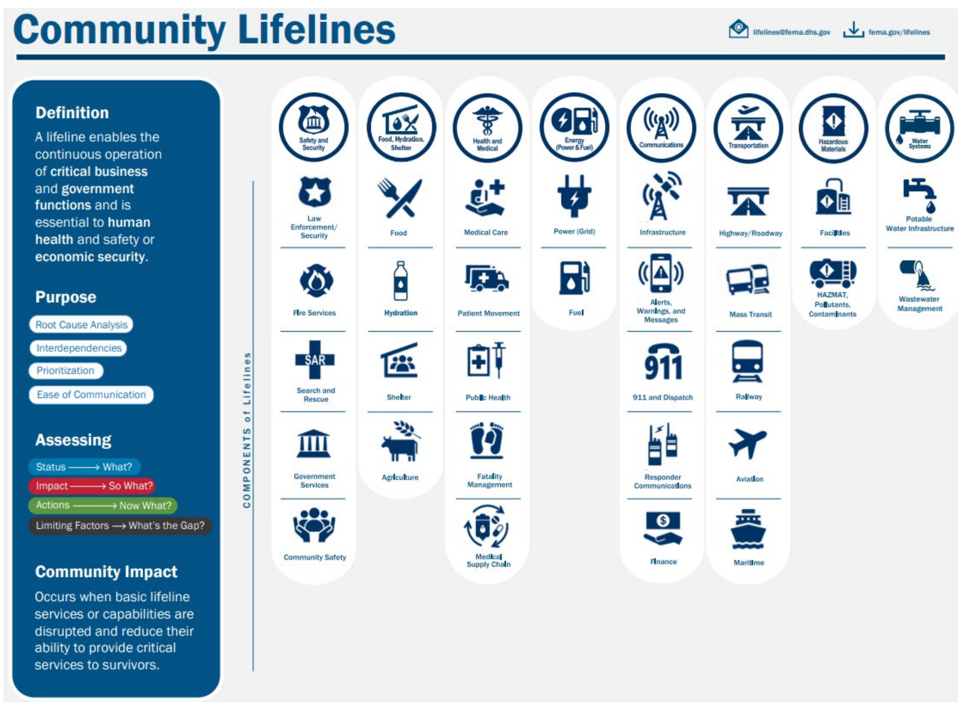

Figure 7. Graphic Showing Federal Emergency Management Agency Community Lifelines, a Tool to Assess Community Impact from Natural Disasters[93]

[91] Federal Emergency Management Agency, "Community Lifelines."

[92] Federal Emergency Management Agency.

[93] Source: Federal Emergency Management Agency.

Each community lifeline is critical to stabilizing an incident and ensuring community recovery by identifying root causes and interdependencies. The climate scenarios within this thesis discuss the impacts of extreme heat on FEMA community lifelines in four distinct communities to better understand the interconnection of heat impacts to emergency management professionals. In addition, these scenarios reflect the expected changes to emergency management requirements at all levels of government to respond to and recover from extreme heat events in different geographies nationwide.

E. SUMMARY

This chapter introduced background information about the threat of extreme heat, as well as prefacing the four extreme heat scenarios discussed in subsequent chapters. In addition, it discussed the FEMA community lifeline framework for analyzing the critical impacts of extreme heat on communities. The following chapters elaborate on these concepts and focus on specific impacts on communities in four distinct cities within the United States: Phoenix, Chicago, Atlanta, and Seattle. This analysis aims to show emergency managers the varied extreme heat impacts that future warming climates will bring.

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III. EXTREME HEAT IMPACT ON PHOENIX, ARIZONA

This scenario focuses on the extreme heat impacts on a hot and dry desert climate like Phoenix by analyzing the likely impacts of extreme heat events at global temperature thresholds of +1.5ºC, +2.0ºC, and +2.5ºC above pre-industrial levels. Although this scenario focuses specifically on Phoenix, many of the impacts are likely to be felt in areas with similar climates.

A. SCENARIO OVERVIEW

Phoenix commonly has high temperatures, with an average of 21 days reaching a temperature of at least 110ºF in an average year.[94] Because of the constantly hot climate, extreme heat has no specific definition in Phoenix, which differs compared to more temperate areas of the country. The lack of a clear definition can lead to confusion, as some Phoenix residents have cited the need to "improve collective definitions" of extreme heat events in community studies, as White-Newsomme et al. argue.[95] Therefore, differentiating what constitutes an "extreme heat" event from a hot summer day proves difficult.

The National Weather Service's Phoenix office developed an experimental "HeatRisk" product to communicate the risk associated with high temperatures in an easy-to-understand way. This product consists of a color-coded scale with five levels, each associated with an increasing risk of heat exposure (see Figure 8). The HeatRisk levels aim to increase awareness of heat-related illnesses and injuries and proactively warn residents of dangerous heat conditions. The HeatRisk tool was subsequently rolled out nationally in 2024 to attempt a unified system for communicating heat risk.

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[94] "Historical Extreme Temperatures in Phoenix and Yuma," National Weather Service, accessed April 19, 2024, https://www.weather.gov/psr/ExtremeTemps.

[95] Jalonne L. White-Newsome et al., "Strategies to Reduce the Harmful Effects of Extreme Heat Events: A Four-City Study," *International Journal of Environmental Research and Public Health* 11, no. 2 (2014): 1965, https://doi.org/10.3390/ijerph110201960.

Level 0 (Green): No elevated risk.	Level 1 (Yellow): Minor Risk for those extremely sensitive to heat, especially those without effective cooling and/or adequate hydration.	Level 2 (Orange): Moderate Risk for those who are sensitive to heat, especially those without effective cooling and/or adequate hydration.	Level 3 (Red): Major Risk for much of the population, especially those who are heat sensitive and those without effective cooling and/or adequate hydration.	Level 4 (Magenta): Extreme Risk for entire population due to long duration heat, with little to no relief overnight.

Figure 8. Levels on National Weather Service Phoenix's HeatRisk Product[96]

Temperatures above 105ºF occur approximately 67 days in a given year in Phoenix at present global temperatures.[97] In a warming scenario of +1.5ºC, this number will increase to approximately 75 days yearly.[98] These statistically significant increases in maximum temperatures start to appear across a wide area of the western United States in a +1.5ºC world, while conclusions remain mixed farther east.[99] In a warming scenario of +2.0ºC, the number of 105ºF temperatures will increase to approximately 90 days yearly.[100] In a warming scenario of +2.5ºC, this number will increase to approximately 115 days yearly.[101] Despite a doubling of hot days between the present day and the +2.5ºC scenario, extreme heat events will occur six times more frequently, and extreme temperatures will last twice as long compared to present conditions.[102] This increase suggests that the already hot climate may see an increase in impact on infrastructure and services with expanding extreme heat events.

Phoenix and surrounding areas have devoted significant effort to combat extreme heat threats over the years. The city has a robust heat program to lessen the effects of

[96] Source: "NWS Phoenix Heat Page," National Weather Service, accessed April 19, 2024, https://www.weather.gov/psr/heat.

[97] "Maricopa County – Phoenix, AZ," The Climate Explorer, accessed April 19, 2024, https://crt-climate-explorer.nemac.org/.

[98] The Climate Explorer.

[99] C. Wobus et al., "Reframing Future Risks of Extreme Heat in the United States," *Earth's Future* 6, no. 9 (2018): 1326, https://doi.org/10.1029/2018EF000943.

[100] The Climate Explorer, "Maricopa County – Phoenix, AZ."

[101] The Climate Explorer.

[102] Susanne Grossman-Clarke et al., "Extreme Summer Heat in Phoenix, Arizona (USA) under Global Climate Change (2041-2070)," *Die Erde* 145, no. 1–2 (2014): 58, https://doi.org/10.12854/erde-145-5.

extreme heat events on the population, including 31 heat response programs spread out across 15 city departments.[103] These programs range from situational awareness strategies to public information campaigns to supporting cool spaces and access to drinking water.[104] The city of Phoenix created a heat-health warning system in 2002 and was one of the first U.S. cities to do so. This system helped educate the local population about the risks associated with heat. In conjunction with similar initiatives in Maricopa County, these programs have created a relatively high heat resiliency compared to many large metropolitan areas.

One factor in resiliency is that the local population is acclimatized to extreme heat and understands the risk since it occurs frequently. In addition, the Maricopa County Health Department has a public messaging campaign at the Phoenix Sky Harbor International Airport to educate unacclimatized visitors about the risks of heat and the benefits of staying hydrated.[105] This program focuses on education for out-of-town guests who may not be aware of the health risks associated with extreme heat.

Despite the high air temperatures, generally low humidity levels have some benefit to the local population. The dry nature of this climate allows efficient perspiration and effective cooling if a person is properly hydrated, even at temperatures around 110ºF. In this scenario, drinking water is vitally important to preventing heat-related illness for people outdoors.

Another benefit to the desert population is that dry air currently allows efficient night cooling. This phenomenon allows nighttime temperatures to recover into the lower 80s and provides some relief. However, as temperatures warm in future climate conditions, nighttime cooling is expected to be less pronounced due to an increase in the humidity of

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[103] City of Phoenix, *City of Phoenix Summer 2023 Heat Response Plan* (Phoenix, AZ: HeatReadyPHX, 2023), 14, https://www.phoenix.gov/heatsite/Documents/Heat%20Response%20Plan%202023%20-%20For%20Gen%20Info%20Packet%20Apr19.pdf.

[104] City of Phoenix, 15–24.

[105] White-Newsome et al., "Strategies to Reduce the Harmful Effects of Extreme Heat Events," 1974.

the air.[106] Therefore, heat stress could remain elevated for a longer period in future extreme heat events.

Despite local efforts to combat the negative health effects of extreme heat, such as the installation of green infrastructure designed to cool temperatures within the city of Phoenix, demographic trends have increased the risk of exposure to extreme heat events. In 2022, Maricopa County saw the largest net increase in population out of any county nationwide.[107] Most of the domestic migration come from more temperate environments. Many newcomers are elderly and prone to heat-related illnesses, with 38 percent of the heat-related fatalities in Maricopa County being older than 65.[108] An increase in elder migration, combined with the threat that extreme heat presents to this age group, suggests increasing local response requirements for emergency managers during future extreme heat events. This situation makes planning more difficult and suggests the need to incorporate meta trends with population migration and climate change-related extreme heat scenarios to better envision future impacts.

Emergency management professionals can expect the following impacts aligned with FEMA's community lifelines during a typical extreme heat event in these three climate scenarios.

1. Safety and Security

Future extreme heat events will affect safety and security, as first responders will have to take precautions to avoid negative health outcomes while working outside. In addition, an increase in heat-related emergency calls will increase demands on first responders, including firefighters, law enforcement, and health workers on the front lines. These demands will be prolonged due to the increased duration of extreme heat events.

[106] Gregg Garfin et al., eds., *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment.* (Washington, DC: Island Press, 2013), 127, https://swccar.arizona.edu/about-report.

[107] "Growth in the Nation's Largest Counties Rebounds in 2022," Census News Releases, March 30, 2023, https://www.census.gov/newsroom/press-releases/2023/population-estimates-counties.html.

[108] Marguerite Sagna, Sanhita Gupta, and Clare Torres, *Mortality and Morbidity from Exposure to Excessive Natural Heat in Arizona, 2005–2015* (Phoenix, AZ: Arizona Department of Health Services, 2017), 8.

The profession that has undergone the most heat-related research is firefighting. Although firefighters have high physical demands on a regular basis, the impact of extreme heat on firefighters is not uniform. One study showed little correlation between work output in firefighters based on temperature due to individual heat tolerance being made up of multiple factors, including personal health.[109] The same study found that the performance of individual firefighters varied significantly and was influenced by rest, rotations, and fluid consumption.[110] Even though an increased rest may combat heat stress on an individual basis, implementing a rest requirement may necessitate additional staffing of first responders to meet mission needs. The rest requirement means that first responder agencies may require additional staffing in the future during extreme heat events.

In a +1.5ºC world, this change will be less pronounced compared to current conditions. However, a +2.0ºC world will mean a 34 percent increase in days above 105ºF.[111] The increase in days above 105ºF could start showing increasing levels of heat stress on the first responder community that could negatively affect safety and security. A +2.5ºC world would further increase this effect, with a doubling of 105ºF+ days in Phoenix. First responders and essential employees who work outdoors will see increasingly negative health and wellness impacts, such as heat stroke and heat exhaustion, regardless of future warming scenarios.

2. Food, Hydration, and Shelter

Although extreme heat events will not directly affect the local food supply since little food is grown in the immediate vicinity, water security will be at the forefront of concern in such an event. At the present time, acute water shortages due to increased water consumption for individual extreme heat events is unlikely. However, prolonged extreme heat will increase the demand for water in Phoenix and surrounding areas. Extreme heat is closely linked with drought in western North America, with drought frequencies becoming

[109] Brianna Larsen et al., "Multiple Days of Heat Exposure on Firefighters' Work Performance and Physiology," *PLoS One* 10, no. 9 (September 17, 2015): 13–14, https://doi.org/10.1371/journal.pone.0136413.

[110] Larsen et al., 14–15.

[111] The Climate Explorer, "Maricopa County – Phoenix, AZ."

significantly higher in the future.[112] In combination with the already arid climate, a drought may further stress groundwater and surface water supply during extended episodes of extreme heat. In addition, the water supply will likely be under additional pressure in the future as an increase in population further taxes the sparse supply. Emergency managers must be prepared for water shortages exacerbated by an increased demand for water.

Phoenix's water supply is currently taxed due to population growth and consumption. Future droughts are expected to become more frequent and longer lasting, exacerbating the issue.[113] In a +1.5ºC, +2.0ºC, and +2.5ºC world, an increase in drought conditions will mean emergency managers will have to consider potable water supplies when making decisions about how to combat extreme heat, including considering the cascading impacts of a water shortage on short-term extreme heat events.

The need for sheltering during an extreme heat event is more unpredictable. Phoenix has existing plans in place to shelter vulnerable and unhoused individuals during heat events. By 2024, the city is expected to be able to house more than 2,000 individuals.[114] While many housed residents have air conditioning, this need would depend on the stability of the power grid.

In a +1.5ºC, +2.0ºC, and +2.5ºC world, extreme heat events may mean an increased need to shelter individuals for a longer period, as extreme heat events become more prevalent and last longer. The need for additional sheltering options may be required, especially considering the expected increase in vulnerable individuals and the population overall. Emergency managers will have to work with shelter providers to ensure this capacity is available in the future, all while considering the interrelated community lifelines that support a shelter, such as energy, health and medical, and safety and security.

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[112] Kumar P. Tripathy et al., "Climate Change Will Accelerate the High-End Risk of Compound Drought and Heatwave Events," *Proceedings of the National Academy of Sciences* 120, no. 28 (2023): 3, https://doi.org/10.1073/pnas.2219825120.

[113] Robert C. Balling and Hermes C. Cubaque, "Estimating Future Residential Water Consumption in Phoenix, Arizona Based on Simulated Changes in Climate," *Physical Geography* 30, no. 4 (2009): 320–21, https://doi.org/10.2747/0272-3646.30.4.308.

[114] City of Phoenix, *City of Phoenix Summer 2023 Heat Response Plan*, 21.

3. Health and Medical

Despite the threat that extreme heat poses for the average person in Phoenix, the city is also resilient due to acclimatization and the fact that the climate has minimal day-to-day variability. One study suggests a lack of evidence between extreme heat events and mortality in Phoenix due to this lack of temperature variability.[115] This lack of correlation can be counterintuitive to some since Phoenix is one of the places most prone to extreme heat. However, since 98 percent of homes and businesses in the Phoenix area use air conditioning, the absence of a link between extreme heat and mortality assumes no cooling interruption. The electricity required for air conditioner usage could be a single point of failure that would have significant negative health outcomes for many Phoenix residents. The health and medical lifeline will likely see the greatest negative impact in a scenario where power is turned off for a significant amount of time, leading to heat-related illness.

Studies from the National Weather Service have found a strong correlation between heat-related illness in Level 2 through Level 4 HeatRisk events. In addition, spikes in heat illness can be seen as temperatures exceed 110ºF. One interesting finding is that an increase in heat-related illnesses is closely related to a relatively sudden spike in temperatures.[116] Figure 9 shows an example of this spike in Maricopa County in 2022. The spike in heat-related illnesses is especially noted early in the summer when the population is less acclimated to extreme heat overall. Emergency managers should be aware of a potential increase in health-related injuries—and potential resource requests—based on both forecasted extreme heat events and rapid temperature rises during the summer.

[115] Scott Greene et al., “An Examination of Climate Change on Extreme Heat Events and Climate–Mortality Relationships in Large U.S. Cities,” *Weather, Climate, and Society* 3, no. 4 (October 2011): 285, https://doi.org/10.1175/WCAS-D-11-00055.1.

[116] National Weather Service, “NWS Phoenix Heat Page.”

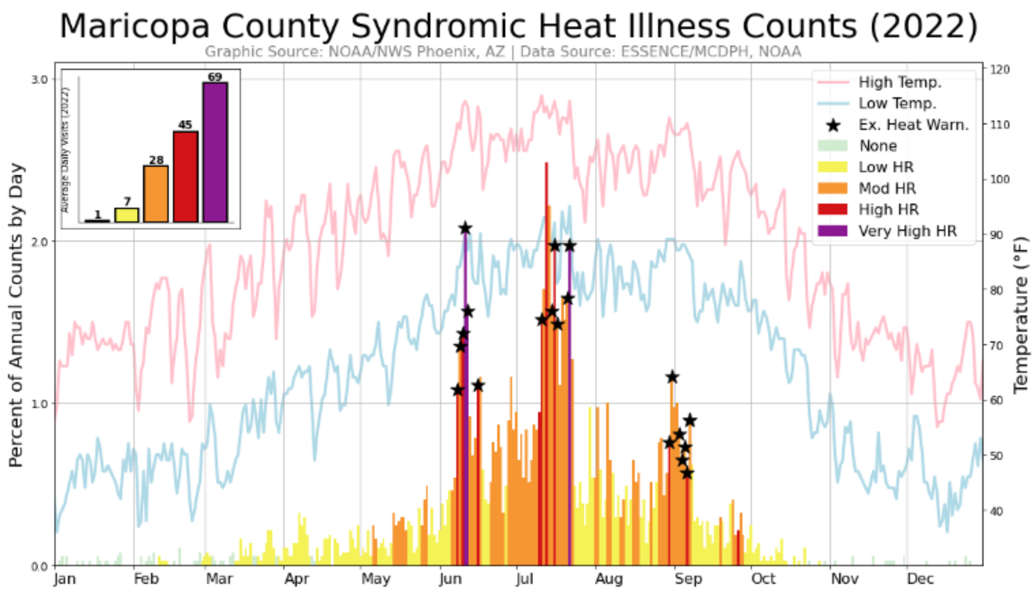

Figure 9. Correlation between HeatRisk Values and Heat Illnesses in Maricopa County in 2022[117]

In addition to illnesses directly related to extreme heat events, other cascading medical concerns are less obvious. In one Australian study, hospital admissions from mental health episodes rose 7.3 percent during extreme heat events compared to average admissions.[118] A rise in mental health-related hospital admittances could tax medical professionals as well as shelter staff, who may not be expecting a coincidental rise in mental health issues during extreme heat events.

Fatality management is also a related concern during extreme heat events. Although heat-related fatalities are not expected to increase dramatically in future climates due to adaptation measures such as air conditioning, cascading impacts related to widespread power outages and subsequent lack of air conditioning pose a significant threat. Emergency managers must plan accordingly for a heat-related mass casualty event to avoid shortages in fatality management supplies, such as the shortages seen during the COVID-19 pandemic.

[117] Source: National Weather Service.

[118] Alana Hansen et al., "The Effect of Heat Waves on Mental Health in a Temperate Australian City," *Environmental Health Perspectives* 116, no. 10 (October 2008): 1369, https://doi.org/10.1289/ehp.11339.

4. Energy (Power and Fuel)

This community lifeline in the Phoenix area of energy, power and fuel, has special considerations. The reliance on stable electricity for air conditioning is crucial to maintaining the health of the population. One study expects heat-related mortality in Phoenix to increase by seven times in the event of a widespread outage during an extreme heat event.[119] The study also suggests a widespread power outage in Phoenix would cause 99 percent of households to be at a high risk of extreme heat exposure indoors and that the increase in temperatures over a short period of time could put Phoenix residents at a greater risk of negative health outcomes compared to cities in other climates if the same scenario were to happen.[120] Therefore, emergency managers must be prepared to provide support to electricity providers to restore power as quickly as possible.

Cascading impacts across many of the other lifelines require increased attention from emergency managers when considering planning. One study shows that a concurrent heatwave and power outage event would require additional cooling centers with generators, and Phoenix has not planned for such an event.[121] The lack of planning for cascading heat and power outage events presents a clear danger without an immediate solution that could result in numerous heat-related illnesses or fatalities. In addition, as extreme heat becomes more common in the future, it could lead to an increased possibility of a deliberate adversarial attack on these energy systems to maximize a negative impact on the population. The population will become even more reliant on air conditioning as temperatures warm. The significant health impacts could make Phoenix a potential target for power grid disruptions during an extreme heat event.

Phoenix is extremely reliant on air conditioning and will likely see air conditioner electricity demand climb by 6.4 percent over the next 30 years, with cooling required 305 days yearly.[122] A 30-year time horizon roughly demonstrates the expected increase in energy

[119] Stone, Jr. et al., "Compound Climate and Infrastructure Events," 6954–6957.

[120] Stone, Jr. et al., 6961.

[121] Stone, Jr. et al., 6962.

[122] San Francisco Federal Reserve Bank, "Extreme Heat's Disparate Impacts on a Local Economy: Phoenix, AZ," *Community Development & District Engagement* (blog), March 26, 2024, https://www.frbsf.org/research-and-insights/blog/community-development/2024/03/26/extreme-heats-impact-on-a-local-economy-phoenix-arizona/.

consumption in a +2.0ºC world. A +2.5ºC climate implies an even greater demand for power resources. Emergency managers must prepare for future power disruptions and include them in all aspects of their future planning.

5. Communications

Extreme heat events in Phoenix will likely not affect communications. Although high temperatures could have a negative impact on some communications equipment, this risk is not expected to be widespread. However, since most communications equipment relies on stable electricity, this interconnection is vital to ensuring communications systems remain functional during extreme heat events. As with many of the other sectors listed in the FEMA lifelines, outdoor personnel may be at risk for heat-related illnesses. The number of communications sector employees is smaller, and much of their work can be accomplished in a climate-controlled location, which limits the threat overall.

6. Transportation

Extreme heat will impact transportation in Phoenix. The impact will be most pronounced in outdoor-intensive transportation industries, such as airports and outdoor logistics facilities, where workers may be directly exposed to such heat. One report suggests that the average outdoor worker in Maricopa County will lose 41 workdays to extreme heat by 2065.[123] This prediction aligns with a +2.0ºC climate. The loss of workdays could equate to 15–22 percent of an outdoor worker's earnings at risk, based on work break recommendations from the CDC in Maricopa County.[124] The decrease in workdays could lead to either increased health problems or decreased wages and productivity in extreme heat conditions for transportation workers exposed to these conditions. Unreliable wages could also lead to potential shortages of essential workers employed in multiple professions and industries that stretch beyond transportation.

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[123] Kristina Dahl and Rachel Licker, *Too Hot to Work: Assessing the Threats Climate Change Poses to Outdoor Workers* (Cambridge, MA: Union of Concerned Scientists, 2021), https://doi.org/10.47923/2021.14236.

[124] Dahl and Licker, 6.

Past extreme heat events have affected transportation infrastructure in Phoenix, including the grounding of airplanes at the airport due to temperatures exceeding the allowable operating thresholds in 2013.[125] Although this type of grounding event happens rarely, emergency managers must consider these potential delays or shortages when undertaking logistics planning efforts in future climates.

7. Hazardous Materials

Hazardous materials are not expected to be impacted by extreme heat events in Phoenix under present conditions or in a +1.5ºC, +2.0ºC, or +2.5ºC world. Although high temperatures could have a negative health impact on personnel handling this type of material outdoors, this risk is not expected to be widespread to the material itself.

8. Water Systems

Water systems are closely related to the food, water, and shelter lifeline mentioned earlier in the scenario. The expected impact on water and wastewater distribution systems is minimal if enough water goes into that system to be treated. This situation is not expected to change during extreme heat events in warming scenarios of +1.5ºC, +2.0ºC, or +2.5ºC, as long as other vital lifelines (such as power) remain functioning.

B. SUMMARY

In sum, Phoenix will see more frequent and longer-lasting extreme heat events in future climate scenarios. The most critical vulnerability will be cascading impacts to a loss of electricity over a large area during an extended period in the Phoenix area. In addition to immediate negative health consequences, this power loss will have cascading impacts in multiple sectors, including water, transportation, and communications. Despite many advances in heat preparedness and resilience in Maricopa County, additional planning efforts should be considered that consider these cascading impacts to mitigate vulnerabilities and create a more resilient community.

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[125] Susan Spierre Clark et al., "The Vulnerability of Interdependent Urban Infrastructure Systems to Climate Change: Could Phoenix Experience a Katrina of Extreme Heat?," *Sustainable and Resilient Infrastructure* 4, no. 1 (2019): 27, https://doi.org/10.1080/23789689.2018.1448668.

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IV. EXTREME HEAT IMPACT ON CHICAGO, ILLINOIS

This scenario focuses on the extreme heat impacts on a temperate climate like Chicago by analyzing the likely impacts of extreme heat events at global temperature thresholds of +1.5ºC, +2.0ºC, and +2.5ºC above pre-industrial levels. Although this scenario focuses specifically on Chicago, many impacts are likely to be felt in areas with four distinct seasons and with cold winters and warm summers.

A. SCENARIO OVERVIEW

Chicago lies in the Midwest on the shores of Lake Michigan and has a climate with four pronounced seasons. Although much of the year is temperate, extreme heat events occur several times per decade. In Chicago, as with much of the eastern part of the country, a combination of heat and humidity often cause extreme heat events.

Despite extreme heat events being relatively infrequent compared to hotter parts of the country, Chicago has experienced several well-known extreme heat events. Extreme heat killed 437 people over a four-day period in 1995.[126] A significant volume of scholarship followed this tragic event. After the event, the city of Chicago instituted an Extreme Weather Operations Plan to increase contact within the elderly community, where many of the heat-related fatalities occurred.[127] This plan is thought to have lessened the death toll during another extreme heat event that occurred in 1999.

The 1995 extreme heat event will likely become much more commonplace in future climate scenarios. Li et al. suggest that an extreme heat day as severe as the 1995 Chicago heat wave would happen less than one day per century in a pre-industrial climate, compared to one day every 35 years today.[128] Hayhoe et al. suggest a similar extreme heat scenario comparable to the 1995 event in Chicago will occur two to five times per decade by 2050,

[126] Naughton et al., “Heat-Related Mortality,” 221.

[127] Luber and McGeehin, “Climate Change and Extreme Heat Events,” 432.

[128] Li, Yuan, and Kopp, “Escalating Global Exposure,” 5.

which is around a +2.0ºC world.[129] All studies analyzed agree that significant temperature rises and more frequent extreme heat events will occur in future climates.

Temperatures above 95ºF occur on approximately nine days in a given year in Chicago at present global temperatures.[130] In a warming scenario of +1.5ºC, this number is expected to increase to approximately 12 days yearly.[131] In a warming scenario of +2.0ºC, the number of 95ºF days will increase to approximately 21 days yearly.[132] In a warming scenario of +2.5ºC, this number will increase to approximately 35 days yearly.[133] The climate projections for Chicago suggest a consistent upward trend in the frequency of days with extreme heat and, therefore, a greater potential for extreme heat impacts.

In analyzing the Chicago scenario, one must consider the regional impact of a global +2.0ºC climate. Perkins-Kirkpatrick and Gibson have shown that although the global average temperature rise may be +2.0ºC, the warming amount could be closer to +3.8ºC at higher latitudes in the United States.[134] These findings correspond with research indicating northern climates will see higher heat mortality by mid-century, as well as the largest overall temperature change.[135]

However, a significant jump in extreme heat prevalence is possible in the future, even under more conservative warming estimates. For example, just +1.5ºC of warming would allow a one-day equivalent temperature of the 1995 extreme heat event to occur more often than every other year.[136] When global temperatures rise to +2.0ºC, extreme

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[129] Katharine Hayhoe et al., "Climate Change, Heat Waves, and Mortality Projections for Chicago," *Journal of Great Lakes Research* 36 (2010): 69, https://doi.org/10.1016/j.jglr.2009.12.009.

[130] "Cook County – Chicago, IL," The Climate Explorer, accessed May 4, 2024, https://crt-climate-explorer.nemac.org/.

[131] The Climate Explorer.

[132] The Climate Explorer.

[133] The Climate Explorer.

[134] Perkins-Kirkpatrick and Gibson, "Changes in Regional Heatwave Characteristics," 1–3.

[135] Vijay S. Limaye et al., "Climate Change and Heat-Related Excess Mortality in the Eastern US," *EcoHealth* 15, no. 3 (2018): 8, https://doi.org/10.1007/s10393-018-1363-0.

[136] Wobus et al., "Reframing Future Risks of Extreme Heat," 1332.

heat days would occur seven times more often.[137] In a +2.0ºC climate, the 1995 extreme heat event would occur more often than yearly, while a +2.5ºC climate would cause such an event to occur nearly three times yearly.[138] These predictions indicate a significant uptick in extreme heat risk for the Midwest due to the increased prevalence of the threat alone.

Extreme heat events will continue to occur more often as global temperatures reach +2.5ºC and above. Although outside the scope of this scenario, studies suggest that the Midwest becomes a worldwide hotspot in moist heat stress in a +3.0ºC climate, suggesting an additional tipping point in extreme heat risk and prevalence.[139] An increasing risk should lead emergency management planners to consider long-term strategies and goals to address the risk.

Extreme heat effects not only depend on exposure, but also the perceived risk of the hazard. Unlike residents of consistently hot and humid parts of the country, residents in the northern Midwest showed a lower perception of this risk in one study than those in coastal areas.[140] Studies have also shown that vulnerable citizens may have underestimated the risk during the 1995 heat event, which led to more casualties as they stayed in unsafe conditions for too long.[141] This finding suggests a need for emergency managers and public health staff to find additional ways to communicate extreme heat risks to certain segments of the population to decrease potential negative health outcomes.

Less intuitive compounding effects can follow extreme heat events, too. Zhang et al. suggest extreme heat events make flood events in the Midwest more likely in the following days because of increased atmospheric moisture.[142] Another study suggests the

[137] Li, Yuan, and Kopp, "Escalating Global Exposure," 5.

[138] Wobus et al., "Reframing Future Risks of Extreme Heat," 1332.

[139] Vecellio et al., "Greatly Enhanced Risk to Humans," 3.

[140] Peter D. Howe et al., "Public Perceptions of the Health Risks of Extreme Heat across U.S. States, Counties, and Neighborhoods," *Proceedings of the National Academy of Sciences of the United States of America* 116, no. 14 (April 2, 2019): 6744, https://www.jstor.org/stable/26698570.

[141] Naughton et al., "Heat-Related Mortality," 221–27.

[142] Zhang and Villarini, "Deadly Compound Heat Stress-Flooding Hazard," 5.

likelihood of flooding events could be approximately 5 percent greater across Illinois immediately after extreme heat events, with even greater trends above 10 percent nearby in Iowa.[143] As extreme heat events happen with increasing frequency, this prevalence means that significant flooding events are also more likely and are connected to extreme heat. Future emergency management planning should consider this tandem impact. Further compounding this threat, strategic attacks against civilian infrastructure must be considered, as increasing geopolitical tensions could allow an adversary to inflict additional damage in the wake of a natural disaster.[144] This risk adds another man-made dimension to the risks associated with extreme heat.

Compared to many other northern cities, Chicago has devoted many resources to combating extreme heat threats after the 1995 event due to its lessons learned. One of the primary changes was developing an Extreme Weather Operations Plan, which instituted cooling centers and telephoned at-risk individuals. These changes possibly lowered the number of deaths in a subsequent extreme heat event in 1999.[145] This outcome shows incremental improvements in changes to policy after significant heat events occurred.

Sometimes, the availability of air conditioning does not necessarily mean that people use it. Historically, extreme heat events have had a greater impact in the Midwest because of the reduced prevalence of climate adaptation measures.[146] One of the most significant adaptation measures is air conditioning. Chicago sees a significant amount of air conditioner usage.

However, air conditioning is still relatively rare in certain parts of the city (including areas near Lake Michigan). Air conditioning prevalence has risen slowly from

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143 Manas Khan, Rabin Bhattarai, and Liang Chen, "Elevated Risk of Compound Extreme Precipitation Preceded by Extreme Heat Events in the Upper Midwestern United States," *Atmosphere* 14, no. 9 (2023): 7, https://doi.org/10.3390/atmos14091440.

144 Kane et al., *Defending the United States Against Critical Infrastructure Attacks*, 6–7.

145 Naughton et al., "Heat-Related Mortality," 227.

146 Luber and McGeehin, "Climate Change and Extreme Heat Events," 430.

around 68 percent in 2013 to 74 percent in 2021.[147] However, many low-income residents who have air conditioning do not turn it on because of the increased electricity bills from running it.[148] This complicating factor shows that public information and awareness about extreme heat risk cannot completely mitigate negative health outcomes.

Emergency management professionals in the Chicago area, as well as the Midwest, can expect the following impacts aligned with FEMA's community lifelines during a typical extreme heat event in these three climate scenarios.

1. Safety and Security

Future extreme heat events will impact safety and security, as first responders will have to take precautions to avoid negative health outcomes while working outside. In addition, an increase in heat-related emergency calls will increase demands on first responders, including firefighters, law enforcement, and health workers on the front lines. These demands will be prolonged due to the increased length of extreme heat events. In a +2.0ºC climate, Chicago would likely have one of the highest numbers of workers exposed to extreme heat of any of the largest cities in the United States due to a warming climate and large population.[149] This likelihood showcases the potential risks for first responders and outdoor workers alike.

Other factors affecting this lifeline include increased rest periods for first responders and extra medical equipment to respond to increasing paramedic calls during extreme heat events. During the 1995 extreme heat event, up to 18 area hospitals were on "bypass status" at one time and could not receive new patients.[150] The response and transportation time increase is also likely during future extreme heat events. As

[147] "2019 National — Heating, Air Conditioning, and Appliances — All Occupied Units," American Housing Survey (AHS) Table Creator, accessed May 28, 2024, https://www.census.gov/programs-surveys/ahs/data/interactive/ahstablecreator.html?s_areas=00000&s_year=2019&s_tablename=TABLE3&s_bygroup1=1&s_bygroup2=1&s_filtergroup1=1&s_filtergroup2=1.

[148] Naughton et al., "Heat-Related Mortality," 221–27.

[149] Dahl and Licker, *Too Hot to Work*, 4.

[150] National Weather Service, *July 1995 Heat Wave*, Natural Disaster Survey Report (Silver Spring, MD: National Oceanic and Atmospheric Administration, 1995), 22, https://www.weather.gov/media/publications/assessments/heat95.pdf.

temperatures spike and extreme heat events last longer, this dual threat could mean an additional burden for first responders in a +1.5ºC, +2.0ºC, and +2.5ºC climate.

2. Food, Hydration, and Shelter

Chicago's water supply comes from Lake Michigan and is both plentiful and stable. The water supply is not expected to change in future climate change scenarios. However, other Midwestern cities may see impacts from extreme heat and drought depending on the location of their water supply. The Greater Chicago area, and the Midwest in general, are major food-producing regions of the country and may see impacts on crops. Droughts resulting from extreme heat events could have a negative effect on food production as well. Although local food supply is unlikely to see significant impacts, droughts followed by extreme heat may cause short-term shortages or price increases.

The city is relatively well prepared to shelter residents in case of an extreme heat event. Chicago has a vast network of 99 cooling centers, which can shelter approximately 26 percent of the population at peak capacity.[151] This capacity demonstrates a significantly better cooling center infrastructure than most cities across the United States. However, these centers still depend on grid power and do not have power backups. One additional consideration for the success of cooling stations is the ability to reach the cooling center easily via public transportation and targeted outreach to vulnerable community members to encourage them to seek a cool location if they are without air conditioning.[152] These considerations have been addressed by new heat planning in the city of Chicago that came about in the wake of the 1995 extreme heat event.

In a +1.5ºC, +2.0ºC, and +2.5ºC world, extreme heat events may mean an increased need to shelter individuals for longer periods as extreme heat events become more prevalent and longer lasting. Events may require additional sheltering options, especially considering the expected increase in vulnerable individuals and the population overall.

[151] Kim et al., "A Comparative Assessment of Cooling Center Preparedness," 6–8.

[152] Juliette M. Randazza et al., "Planning to Reduce the Health Impacts of Extreme Heat: A Content Analysis of Heat Action Plans in Local United States Jurisdictions," *American Journal of Public Health* 113, no. 5 (May 2023): 563–66, https://doi.org/10.2105/AJPH.2022.307217.

Emergency managers will have to work with shelter providers to ensure this capacity is available in the future, all while considering the interrelated community lifelines that support a shelter, such as energy, health and medical, and safety and security.

3. Health and Medical

As demonstrated by the 1995 extreme heat event in Chicago, the city is very vulnerable to negative health outcomes during abnormally hot weather. Part of this vulnerability is a relatively high number of socially vulnerable citizens and the lower prevalence of air conditioning compared to many places in the Midwest. In addition, although some cities show the population becomes more acclimatized over the course of a summer to heat, Chicago's population does not show this characteristic.[153] For example, Cook County had 11 percent more hospital admissions than average during the mid-summer extreme heat event in 1995.[154] Patients over 65 in age accounted for 35 percent more admissions than average.[155] In total, 59 percent of the excess admissions were directly linked to heat-related illnesses.[156] These factors increase the prevalence of negative health outcomes and a potential need for emergency management assistance and coordination during extreme heat events if medical infrastructure becomes overwhelmed.

One significant driver of extreme heat illnesses and deaths is humidity. Extreme heat events in Chicago normally coincide with high humidity levels, which keep temperatures high in the daytime and overnight. Several studies show that high nighttime temperatures prevent the body from recovering from the hot afternoon temperatures, which

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153 Hayhoe et al., "Climate Change, Heat Waves, and Mortality Projections for Chicago," 69.

154 Jan C Semenza et al., "Excess Hospital Admissions during the July 1995 Heat Wave in Chicago," *American Journal of Preventive Medicine* 16, no. 4 (May 1999): 269, https://doi.org/10.1016/S0749-3797(99)00025-2.

155 Semenza et al., 269.

156 Jan C Semenza et al., "Excess Hospital Admissions during the July 1995 Heat Wave in Chicago," *American Journal of Preventive Medicine* 16, no. 4 (May 1, 1999): 1, https://doi.org/10.1016/S0749-3797(99)00025-2.

increases the risk of heat illness by maintaining a high level of heat stress on the body.[157] Hartz et al. suggest a high heat index is even more important than high temperatures as a predictor of heat-related deaths in Chicago.[158] This scenario shows the need for emergency managers to be aware of heat trends and temperature data to attain better situational awareness to support medical staff in such a situation.

Some of the same health-related impacts can be seen in other major metropolitan areas in the Midwest. Nationwide studies have shown that heat-related mortality has been highest in the Midwest and Northeast compared to other parts of the United States.[159] Anderson and Bell suggest that for every degree Fahrenheit of average temperature increase during a heat wave, mortality climbs by 3.22 percent in the Midwest.[160] Hartz et al. suggest heat-related fatalities "begin to climb exponentially" in Chicago once the temperature rises to nearly 90ºF and the heat index rises above 97ºF.[161] These metrics suggest a more significant tipping point of health concerns in Chicago than in other cities.

Fatality management is also a related concern during extreme heat events. One of the first indications that the 1995 extreme heat event was a significant event was the arrival of victims at the city's morgue.[162] Emergency managers must plan accordingly for a heat-related mass casualty event to avoid shortages in fatality management supplies, such as the shortages seen during the COVID-19 pandemic.

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157 Tianqi Chen et al., "Time-Series Analysis of Heat Waves and Emergency Department Visits in Atlanta, 1993 to 2012," *Environmental Health Perspectives* 125, no. 5 (2017): 157009–6, https://doi.org/10.1289/EHP44; Greene et al., "An Examination of Climate Change," 283; Wobus et al., "Reframing Future Risks of Extreme Heat," 1328; and Katharine M. Willett and Steven Sherwood, "Exceedance of Heat Index Thresholds for 15 Regions under a Warming Climate Using the Wet-Bulb Globe Temperature," *International Journal of Climatology* 32, no. 2 (2012): 161–66, https://doi.org/10.1002/joc.2257.

158 Donna A. Hartz et al., "Climate and Heat-Related Emergencies in Chicago, Illinois (2003–2006)," *International Journal of Biometeorology* 56 (2012): 82, https://doi.org/10.1007/s00484-010-0398-x.

159 Luber and McGeehin, "Climate Change and Extreme Heat Events," 430.

160 G. Brooke Anderson and Michelle L. Bell, "Heat Waves in the United States: Mortality Risk during Heat Waves and Effect Modification by Heat Wave Characteristics in 43 U.S. Communities," *Environmental Health Perspectives* 119, no. 2 (February 2011): 212, ProQuest.

161 Hartz et al., "Climate and Heat-Related Emergencies in Chicago, Illinois (2003–2006)," 81.

162 National Weather Service, *July 1995 Heat Wave*, 41.

Several studies have found that air conditioning is the most effective mitigation measure to prevent negative health outcomes during a heatwave. During the 1999 heat wave in Chicago, Naughton et al. found that a working air conditioner would have prevented 92 percent of heat-related deaths of people living alone and the homebound.[163] Many low-income and fixed-income residents chose to use fans instead of air conditioning to save money on electricity costs, which ultimately cost lives. Counterintuitively, research suggests that indoor fans can increase heat stress when the heat index exceeds 99ºF by blowing air warmer than the body temperature over the skin.[164] This finding suggests that better communication about the risks of relying on fans and not running air conditioners should be considered during future extreme heat events.

During some extreme heat events in Chicago, much of the population is aware of upcoming heat waves. During the 1999 extreme heat event, 90 percent of subjects were aware of the heat warning, and 95 percent said they knew the danger of extreme heat.[165] However, most of the fatalities affected older residents with medical conditions who were low income, lived alone, and did not leave home daily.[166] Younger people are not immune to negative health effects from extreme heat. During the 1995 extreme heat event in Chicago, psychiatric illnesses were twice as prevalent in younger age groups compared to older groups.[167] This finding suggests that heat messaging is more than just communicating the threat. Instead, it requires specific and tailored messages from trusted sources, such as family, home healthcare workers, and neighbors for individuals who are most at risk of negative health outcomes.

Unlike the Sun Belt and other parts of the country, where aging populations contribute greatly to extreme heat risk, the Midwest is expected to see flatter increases in

[163] Naughton et al., "Heat-Related Mortality," 224.

[164] Luber and McGeehin, "Climate Change and Extreme Heat Events," 432.

[165] Naughton et al., "Heat-Related Mortality," 223–24.

[166] Naughton et al., 224.

[167] Jessica Abbinett et al., *Heat Response Plans: Summary of Evidence and Strategies for Collaboration and Implementation* (Atlanta, GA: Centers for Disease Control and Prevention), 10, accessed January 25, 2024, https://www.cdc.gov/climateandhealth/docs/HeatResponsePlans_508.pdf.

aging populations in the future.[168] However, the risk to aging and vulnerable citizens is still high. The faster growth of occurrences of heat extremes compared to other parts of the country accounts for this increased rate.[169] Figure 10 shows the expected heat-related change in mortality by county of elderly individuals by the year 2069, which roughly corresponds with the expectations of a +2.0ºC climate. The figure suggests that heat-related mortality will not just affect large urban areas but threatens a large swath of the Midwest and Northeast. These findings suggest that the problem spans urban and rural areas as a growing issue that will become more prevalent in a +2.0ºC climate. Although the health and medical lifeline has traditionally seen the greatest impacts from extreme heat events, this effect is also likely in a +1.5ºC, +2.0ºC, and +2.5ºC world.

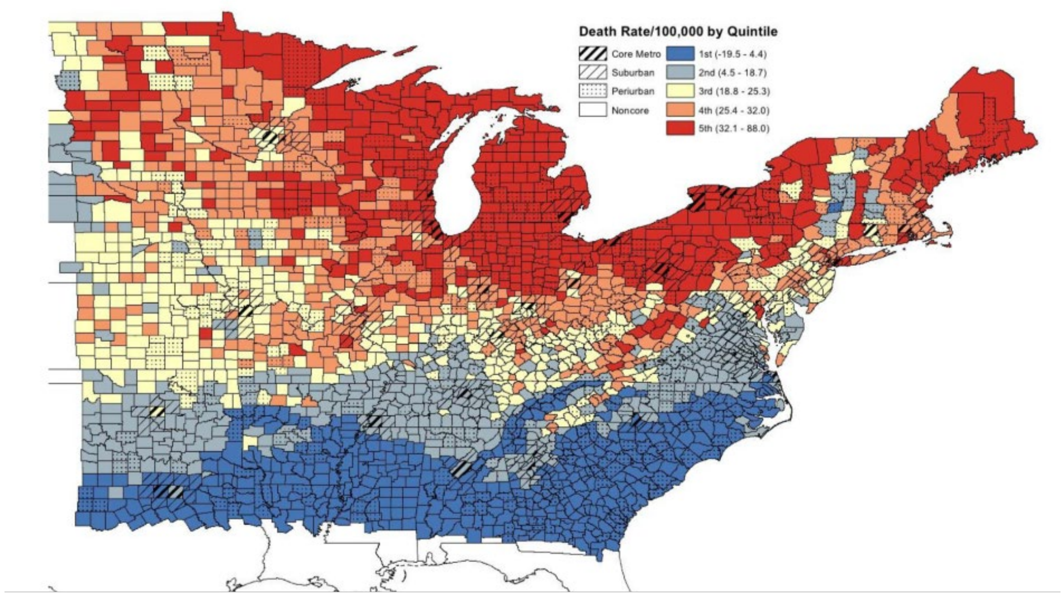

Figure 10. Heat-Related Mortality Change for the Population Aged 65+ by 2069[170]

[168] Deborah Carr, Giacomo Falchetta, and Ian Sue Wing, "Population Aging and Heat Exposure in the 21st Century: Which U.S. Regions Are at Greatest Risk and Why?," *The Gerontologist* 64, no. 3 (2024): 8, https://doi.org/10.1093/geront/gnad050.

[169] Carr, Falchetta, and Sue Wing, 8.

[170] Source: Limaye et al., "Climate Change and Heat-Related Excess Mortality in the Eastern US," 16.

4. Energy (Power and Fuel)

Chicago is no more (or less) vulnerable to power outages and electrical grid disruptions than elsewhere in the United States. However, little research has been done to determine what health consequences would follow a grid disruption during an extreme heat event in Chicago. As with all scenarios analyzed, heat-related illnesses would likely increase dramatically in the event of a widespread power outage during such an event. Therefore, emergency managers must be prepared to support electricity providers to restore power as quickly as possible.

Chicago would see summer electricity demand climb by 12 percent in a +1.5ºC climate, which will strain existing infrastructure even without an extreme heat event.[171] In a +2.0º climate, electricity demand will increase by nearly 20 percent.[172] This situation may mean a greater incidence of grid disruptions, or "brownouts," in future climates if electricity demand exceeds supply. Therefore, emergency managers must prepare for future power disruptions and include them in all aspects of their future planning.

5. Communications

Extreme heat events in Chicago will likely affect communications. Although high temperatures could have a negative impact on some communications equipment, this risk will not be widespread. However, since most communications equipment relies on stable electricity, this interconnection is vital to ensuring communications systems remain functional during extreme heat events. As with many of the other sectors listed in the FEMA lifelines, outdoor personnel may be at risk for heat-related illnesses. The number of communications sector employees is smaller, and much of their work can be accomplished in a climate-controlled location, which limits the threat overall.

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[171] Obringer Renee, Rohini Kumar, and Nateghi Roshanak, "Managing the Water–Electricity Demand Nexus in a Warming Climate," *Climatic Change* 159, no. 2 (2020): 247–48, https://doi.org/10.1007/s10584-020-02669-7.

[172] Renee, Kumar, and Roshanak, 247.

6. Transportation

Extreme heat will hamper the transportation lifeline in Chicago. The impact will be most pronounced in outdoor-intensive transportation industries, such as airports and outdoor logistics facilities, where workers may be directly exposed to such heat. In a +2.0ºC climate, Chicago will likely have one of the highest numbers of workers exposed to extreme heat of any of the largest cities due to a warming climate and large population.[173] This temperature increase threatens productivity and poses a challenge across all sectors requiring outdoor work, including in the transportation industry.

7. Hazardous Materials

The hazardous materials lifeline will likely remain the same in extreme heat events in Chicago under present conditions or in a +1.5ºC, +2.0ºC, or +2.5ºC world. Although high temperatures could have a negative health impact on personnel handling this type of material outdoors, this risk to the material itself will not likely be widespread.

8. Water Systems

The water system lifeline is closely related to the food, water, and shelter community lifeline mentioned earlier in the scenario. One significant difference in Chicago is the abundance of water since the city's water source is Lake Michigan. This supply eliminates the possibility of the city running out of water because of drought or prolonged extreme heat events. Since extreme heat events coincide with maximum water usage, an emergency manager's planning efforts for such an event should consider cascading water system failures.

B. SUMMARY

In summary, Chicago will see more frequent and longer-lasting extreme heat events in future climate scenarios. The most critical vulnerability will include cascading impacts due to a loss of electricity over a large area during an extended period in the Chicago area. In addition to immediate negative health consequences, this power loss will have cascading

[173] Dahl and Licker, *Too Hot to Work*, 4.

impacts in multiple sectors, including water, transportation, and communications. Many advances have been made in heat preparedness and resilience in Chicago since the 1995 extreme heat event; however, the population remains vulnerable because of the lack of acclimatization to heat, socioeconomics, and rapid increases in extreme heat events in the future. Additional planning efforts might consider cascading impacts to mitigate vulnerabilities and create a more resilient community.

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V. EXTREME HEAT IMPACT ON ATLANTA, GEORGIA

This scenario focuses on the extreme heat impacts on a warm and humid climate like Atlanta by analyzing the likely impacts of extreme heat events at global temperature thresholds of +1.5ºC, +2.0ºC, and +2.5ºC above pre-industrial levels. Although this scenario focuses specifically on Atlanta, many of the impacts are likely to be felt in similar climates across the South, Southeast, and Mid-Atlantic that are normally hot and humid during the summer. This scenario is, therefore, indicative of impacts across a much larger portion of the country that has a similar climate.

A. SCENARIO OVERVIEW

Atlanta is a large metropolitan area and the capital of the state of Georgia. The city routinely sees hot and humid weather in the warm months of the year, with an average of 15 to 30 days reaching a temperature of at least 95ºF in a normal year.[174] Hot temperatures are common, but no specific definition of extreme heat exists in Atlanta. The National Weather Service office in nearby Peachtree City, Georgia, will issue an excessive heat warning when heat index values are expected to rise above 110ºF.[175] However, much of the summer is spent with heat indices hovering around 100ºF daily. This relatively consistent temperature can lead to negative extreme heat impacts, but it also fosters acclimatization to heat, which is seen as a mitigating factor in negative health outcomes.

In Atlanta, like many humid areas of the country, the main driver of the extreme heat conversation is the combination of heat and humidity. The region's proximity to the Gulf of Mexico provides regular influxes of moisture year-round, but especially in the summer months when temperatures are warmest. During extreme heat events, this moisture causes moist heat stress. Moist heat stress makes it difficult for the body to cool itself

[174] Environmental Protection Agency, "What Climate Change Means for Georgia," EPA 430-F-16-012 (Washington, DC: Environmental Protection Agency, August 2016), 2, https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-ga.pdf.

[175] Hawkins, Brown, and Ferrell, "Assessment of NOAA National Weather Service Methods," 10.

through perspiration, as environmental moisture levels remain high and prevent the perspiration from evaporating.

The southeastern United States will see several changes in future climates. Climate projections indicate that eastern parts of the United States may see rain more frequently due to warming, which is different from parts of the western United States that are expected to become drier.[176] Increasing hurricane activity is also expected, increasing precipitation and moisture in the region.[177] This increase in moisture will further add to moist heat stress during the summer months. The laws of thermodynamics state that the amount of water vapor in the atmosphere can increase by 7 percent for every 1ºC rise in temperature.[178] Buzan and Huber suggest that the eastern United States will be a moist heat stress "hotspot" in the future, where impacts to individuals may be greatest worldwide in warmer climates.[179] These hotspots will see an outsized focus on negative health impacts due to extreme heat events compared to other parts of the world. Therefore, emergency managers and public health professionals must focus on mitigation measures to overcome these expected impacts.

Temperatures above 95ºF occur approximately 18 days in a given year in Atlanta at present global temperatures.[180] In a warming scenario of +1.5ºC, this number will increase to approximately 23 days yearly.[181] In a +2.0ºC climate, maximum summer temperature changes are statistically significant for the southeastern United States.[182] The change from 1.5ºC to 2.0ºC will reduce the return period of heat waves by more than 60

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176 U.S. Global Change Research Program, "Climate Science Special Report" (Washington, DC: U.S. Global Change Research Program), accessed May 24, 2024, https://science2017.globalchange.gov/chapter/7/.

177 U.S. Global Change Research Program.

178 Buis, "Steamy Relationships."

179 Jonathan R. Buzan and Matthew Huber, "Moist Heat Stress on a Hotter Earth," *Annual Review of Earth and Planetary Sciences* 48, no. 1 (2020): 643, https://doi.org/10.1146/annurev-earth-053018-060100.

180 "Fulton County – Atlanta, GA," The Climate Explorer, accessed May 20, 2024, https://crt-climate-explorer.nemac.org/.

181 The Climate Explorer.

182 Wobus et al., "Reframing Future Risks of Extreme Heat," 1326.

percent.[183] This change means a warming scenario of +2.0ºC will cause the number of 95ºF temperatures to increase to approximately 35 days yearly.[184] In a warming scenario of +2.5ºC, this number will increase to approximately 63 days yearly.[185] For example, one study reported that children in the southeastern United States would spend half of their summers experiencing heat waves that would have occurred only three days a year in previous generations.[186] This increase suggests that the already hot climate may see an increase in impact on infrastructure and services with expanding extreme heat events.

As with most major cities across the globe, the urban heat island effect keeps Atlanta's inner core even warmer. The temperatures of the urban core of Atlanta are the highest in the city and are 2ºC higher compared to surrounding areas.[187] Despite this urban heat island effect, Atlanta is also heavily forested, which increases resilience to extreme heat and lessens the impact on some of the affected communities.[188] This urban core also coincides with some of the least vulnerable populations to extreme heat impacts. Therefore, a majority of the most vulnerable population of Atlanta cluster in areas with the least negative health impacts due to extreme heat, which is unlike many large urban cities.

One prolonged extreme heat event from August 2007 in Atlanta featured nine days above 100ºF and an all-time August record temperature of 104ºF.[189] Atlanta's 2007 extreme heat event would become more commonplace in a warming climate. Although the probability of seeing one day meeting that level of extreme heat is less than once every 10 years in a pre-warming climate, +1.5ºC of warming would make that extreme heat event

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183 Dosio et al., "Extreme Heat Waves under 1.5 °C and 2 °C Global Warming," 6.

184 The Climate Explorer, "Fulton County – Atlanta, GA."

185 The Climate Explorer.

186 Wobus et al., "Reframing Future Risks of Extreme Heat," 1334.

187 Nkosi Muse et al., "Heat Exposure and Resilience Planning in Atlanta, Georgia," *Environmental Research: Climate* 1, no. 1 (2022): 11, https://doi.org/10.1088/2752-5295/ac78f9.

188 Muse et al., 14.

189 Yan Zhou and J. Marshall Shepherd, "Atlanta's Urban Heat Island under Extreme Heat Conditions and Potential Mitigation Strategies," *Natural Hazards* 52, no. 3 (March 2010): 640, https://doi.org/10.1007/s11069-009-9406-z.

occur more often than every other year.[190] In a +2.0ºC climate, that extreme heat event would occur nearly two times yearly, while a +2.5ºC climate would occur nearly four times yearly.[191] Therefore, the increase in extreme heat prevalence will continue to increase much more rapidly in the future.

Atlanta has some mitigation measures that lessen the impacts of extreme heat events on the population. Air conditioning greatly lessens heat impacts on the population. Over 94 percent of residential structures in Atlanta have access to air conditioning.[192] This mitigation measure allows most people inside of a structure to cool off, yet also increases the risk of power disruption when extreme heat events tax the electrical grid.

Another factor in resiliency is that the local population is acclimatized to hot and humid weather. Because of Atlanta's geographical location, temperatures rarely fluctuate significantly during the hottest months of the year. Even though it is hot, the steady temperature decreases overall sensitivity to heat, which is more common in northern climates. Studies have shown a steady temperature decreases the negative health outcomes associated with extreme heat as the body acclimates to the environment.

Despite the mitigation and resilience measures, demographic trends will further increase risk in Atlanta. Atlanta is already one of the fastest-growing metropolitan areas in the United States, and the 21-county Atlanta region is expected to grow by nearly 30 percent by 2050.[193] More significantly, the number of adults over the age of 75 is expected to increase to nearly 12 percent of the population by 2050, compared to less than 5 percent in 2020.[194] The increase of adults most vulnerable to negative health outcomes of extreme heat will likely increase the burden on medical facilities. It may also increase the chances of negative cascading impacts during extreme heat events. Atlanta is just one of many

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[190] Wobus et al., "Reframing Future Risks of Extreme Heat," 1332.

[191] Wobus et al., 1332.

[192] Stone, Jr. et al., "Compound Climate and Infrastructure Events," 6960.

[193] Paul Donsky, "Metro Atlanta Population to Reach 7.9 Million by 2050, ARC Forecasts Show," Atlanta Regional Commission, *ARC* (blog), February 14, 2024, https://atlantaregional.org/news/the-atlanta-region/metro-atlanta-population-to-reach-7-9-million-by-2050-arc-forecasts-show/.

[194] Donsky.

locations across the Southeast and Southwest that must prepare for an outsized influx of older residents, which introduces policy questions surrounding extreme heat planning and whether high health risk individuals should be living in high heat risk locations.

Even though the southeastern United States is at risk of negative heat-related impacts, relatively little scholarly research or planning has been done compared to other parts of the United States. In recent years, municipal governments in Atlanta and the surrounding areas have only done limited planning around the specific threat of extreme heat.[195] This lack of planning limits the overall awareness of the area's extreme heat risk. It suggests incorporating meta-trends with domestic population migration and climate change-related extreme heat scenarios to envision future impacts better.

Emergency management professionals can expect the following impacts aligned with FEMA's community lifelines during a typical extreme heat event in these three climate scenarios.

1. Safety and Security

Many of the impacts felt by safety and security personnel in Phoenix are also felt in Atlanta. The largest impact for first responders in future extreme heat events will be precautions that they must take to avoid negative health outcomes while working outside. The Southeast is projected to face high labor losses and increased heat risk to outdoor workers in general.[196] In addition, an increase in heat-related emergency calls will increase demands on first responders, including firefighters, law enforcement, and health workers on the front lines. These demands will be prolonged due to the increase in the length of extreme heat events. They may include increasing staff during anticipated extreme heat events to cover rest and recuperation for responders who have been exposed to extreme heat events.

[195] Muse et al., "Heat Exposure and Resilience Planning in Atlanta, Georgia," 14.

[196] Allison R. Crimmins et al., eds., *Fifth National Climate Assessment* (Washington, DC: U.S. Global Change Research Program, 2023), 32, https://doi.org/10.7930/NCA5.2023.CH1.

2. Food, Hydration, and Shelter

Although extreme heat events will likely not affect the local food supply, water security will be at the forefront of concern in such an event. At the present time, acute water shortages due to increased water consumption for individual extreme heat events is unlikely. However, prolonged extreme heat will increase the demand for water in Atlanta and surrounding areas.

Atlanta's water supply is currently taxed due to limited surface water supplies, population growth, and consumption. Although precipitation is expected to increase slightly across the Southeast, the limited storage will prevent much of this additional precipitation from helping accommodate water needs. In a +1.5ºC, +2.0ºC, and +2.5ºC world, extreme heat will not have a significant impact on changing water supply availability. However, individual extreme heat incidents could further tax a water supply that is currently under strain by demographic changes. An unreliable water supply may mean emergency managers will have to consider potable water supplies when deciding how to combat extreme heat, including considering the cascading impacts of a water shortage on short-term extreme heat events.

The need for sheltering during an extreme heat event may increase, especially as individual extreme heat events get longer and more frequent. Atlanta has existing plans in place to shelter vulnerable and unhoused individuals during heat events, but the current shelter footprint is limited. For example, the five cooling centers in Atlanta would only be capable of housing 1 percent of the population.[197] An additional concern is that Atlanta's cooling center plans do not require backup power capabilities to ensure that they remain functional in the event of a power outage.[198] A coinciding power outage could limit the usefulness of open shelters in the event of an extreme heat event.

In a +1.5ºC, +2.0ºC, and +2.5ºC world, extreme heat events may mean an increased need to shelter individuals longer as extreme heat events become more prevalent and last longer. The need for additional sheltering options may be required, especially considering

[197] Stone, Jr. et al., "Compound Climate and Infrastructure Events," 6962.

[198] Stone, Jr. et al., 6962.

the expected increase in vulnerable individuals and the population overall. Emergency managers will have to work with shelter providers to ensure this capacity is available in the future, all while considering the interrelated community lifelines that support a shelter, such as energy, health and medical, and safety and security.

3. Health and Medical

Despite the threat that extreme heat and high humidity pose for the average person in Atlanta, the city is also resilient due to acclimatization and minimal day-to-day variability in climate. In general, hot climates tend to have less of an impact on the health and medical lifeline in extreme heat events compared to more temperate climates due to acclimatization and the prevalence of air conditioning.[199] In Atlanta, 94 percent of residential structures have access to air conditioning.[200] However, the lack of a link between extreme heat and mortality assumes no cooling interruption. The electricity required for air conditioner usage could be a single point of failure that would have significant negative health outcomes for many Atlanta residents. This vulnerability may also allow bad actors to coordinate a power infrastructure attack to maximize suffering and fatalities during an extreme heat event.

Negative health impacts can especially be seen in Atlanta's humid climate, which is less conducive to efficient evaporative cooling from sweating.[201] The health and medical lifeline will likely see the greatest negative impact when power is turned off for a significant amount of time, leading to heat-related illness. One study suggests Atlanta could see 350,000 people killed in a prolonged heatwave without access to electricity and air conditioning.[202] This type of event would obviously require a huge emergency management response that has not been planned for by local officials.

The spike in heat-related illnesses is especially noted later in the summer, which is unlike other parts of the country. One study in Atlanta that analyzed heat-related

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[199] Luber and McGeehin, "Climate Change and Extreme Heat Events," 430.

[200] Stone, Jr. et al., "Compound Climate and Infrastructure Events," 6960.

[201] Luber and McGeehin, "Climate Change and Extreme Heat Events," 430.

[202] Stone, Jr. et al., "Compound Climate and Infrastructure Events," 6962.

emergency room visits found that later timing in the year caused more emergency room visits, along with heat duration and intensity.[203] The anomaly is likely due to the persistent heat and humidity common in the Atlanta area's climate, with cumulative effects of taxing the body as duration is the likely culprit.[204] Emergency management professionals must be aware of the need for increasing support for health and medical providers in the event of long-duration events, with special considerations taken to plan and alert the public as the summer heat persists.

One study also found that high minimum temperatures were just as important as high maximum temperatures in assessing negative health impacts during an extreme heat event.[205] The importance of high minimum temperatures suggests that emergency managers in Atlanta and surrounding areas should consider opening 24-hour shelters and increase situational awareness efforts to determine the accumulated heat stress on the overall population to better anticipate the potential resource needs of a shelter.

4. Energy (Power and Fuel)

Special concerns are associated with this community lifeline in the Atlanta area. The reliance on stable electricity for air conditioning is crucial to maintaining the population's health. Atlanta has no specific plan to address a compounding blackout event during an extreme heat event.[206] The lack of planning for cascading heat and power outage events presents a danger without an immediate solution that could result in many heat-related illnesses or fatalities.

Several examples of similar cascading power outages and extreme heat events have been seen across the southeastern United States. In 2017, heat-related deaths in Florida in the wake of Hurricane Irma surged because of an extensive power outage, especially within nursing homes. Although the tropical risk may be smaller in the Atlanta area, its similar climate could lead to a similar outcome in deaths during outages. Therefore, emergency

[203] Chen et al., "Time-Series Analysis of Heat Waves," 057009–7.

[204] Anderson and Bell, "Heat Waves in the United States," 217.

[205] Chen et al., "Time-Series Analysis of Heat Waves," 057009–7.

[206] Stone, Jr. et al., "Compound Climate and Infrastructure Events," 6962.

managers in Atlanta must be prepared to provide support to electricity providers to restore power as quickly as possible to ensure the safety of the population.

Atlanta is extremely reliant on air conditioning. Georgia is expected to see air electricity demand climb by 18.1 percent from 2011 to 2050 due to population influx and increased air conditioning demands in a warmer climate.[207] The increased demand is an estimate assuming current population trends continue. However, the 2050 time horizon roughly demonstrates the expected increase in energy consumption in a +2.0ºC world. A +2.5ºC climate implies an even greater demand for power resources during extreme heat events. Emergency managers must prepare for future power disruptions and include them in all aspects of their future planning.

5. Communications

Extreme heat events in Atlanta will likely not affect communications. Although high temperatures could have a negative impact on some communications equipment, this risk will not be widespread. However, since most communications equipment relies on stable electricity, this interconnection ensures communications systems remain functional during extreme heat events. As with many of the other sectors listed in the FEMA lifelines, outdoor personnel may be at risk for heat-related illnesses. The number of communications sector employees is smaller, and much of their work can be accomplished in a climate-controlled location, which limits the threat overall.

6. Transportation

Extreme heat will affect the transportation lifeline in Atlanta. The impact will be most pronounced in outdoor-intensive transportation industries, such as airports and outdoor logistics facilities, where workers may be directly exposed to such heat. One report suggests that the average outdoor worker in Fulton County will lose about two weeks of work to extreme heat by 2065.[208] This prediction aligns with a +2.0ºC climate. The loss

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[207] Melissa Allen et al., "Impacts of Climate Change on Sub--regional Electricity Demand and Distribution in the Southern United States," *Nature Energy*, 2016, 5, https://doi.org/10.1038/nenergy.2016.103.

[208] Dahl and Licker, *Too Hot to Work*.

of workdays could equate to about 5 percent of an outdoor worker's earnings at risk, based on work break recommendations from the CDC in Fulton County.[209] The decrease in workdays could lead to either increased health problems or decreased wages and productivity in extreme heat conditions for transportation workers exposed to these conditions. Unreliable wages could also lead to potential shortages of essential workers employed in multiple professions and industries that stretch beyond transportation.

7. Hazardous Materials

The hazardous materials lifeline is not expected to be impacted by extreme heat events in Atlanta under present conditions or in a +1.5ºC, +2.0ºC, or +2.5ºC world. Although high temperatures could have a negative health impact on personnel handling this type of material outdoors, requiring increased exposure to heat and the need to take more frequent breaks, this risk is not expected to be widespread to the material itself.

8. Water Systems

The water system lifeline is closely related to the food, water, and shelter community lifeline mentioned earlier in the scenario. The expected impact on water and wastewater distribution systems is minimal so long as enough water goes into that system to be treated. This situation is not expected to change during extreme heat events in warming scenarios of +1.5ºC, +2.0ºC, or +2.5ºC, as long as other vital lifelines (such as power) remain functioning.

B. SUMMARY

In summary, Atlanta will see more frequent and longer-lasting extreme heat events in future climate scenarios. The most critical vulnerability will be cascading impacts to a loss of electricity over a large area during an extended period in the Atlanta area. In addition to immediate negative health consequences, this power loss will have cascading impacts in multiple sectors, including water, transportation, and communications. Cascading impacts resulting from extreme heat-related power outages should be considered to mitigate vulnerabilities and create a more resilient community.

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[209] Dahl and Licker, 6.

VI. EXTREME HEAT IMPACT ON SEATTLE, WASHINGTON

This scenario focuses on the extreme heat impacts on a normally temperate maritime climate like Seattle by analyzing the likely impacts of extreme heat events at global temperature thresholds of +1.5ºC, +2.0ºC, and +2.5ºC above pre-industrial levels. Although this scenario focuses specifically on Seattle, many of the impacts are likely to be felt in areas with a similar climate, from the Pacific Northwest down to coastal California. This scenario focuses on many of the most densely populated parts of the country, which would see widespread health impacts in such an event.

A. SCENARIO OVERVIEW

Seattle is the most populous city in the Pacific Northwest and is geographically located where marine influence significantly influences weather and climate in the community. Because of the latitude and cool water temperatures, extreme heat events are relatively rare along the coast of Washington. However, even populations near the ocean that historically have only seen heat waves on rare occasions will have meaningful exposure to extreme heat in the future.[210] Extreme heat events in the Pacific Northwest are examples of low-probability/high-impact events that will see an increasing probability of occurring. The increase in heat exposure shows the need for comprehensive planning and analysis of Seattle and surrounding areas for emergency managers in future warmer climates.

One of the most notable and memorable extreme heat events in Seattle and the Pacific Northwest occurred in 2021. In late June 2021, the Pacific Northwest experienced an all-time record extreme heat event, with temperatures reaching 108ºF in Seattle.[211] The widespread high temperatures led to power outages, wildfires, and negative human health

[210] Vahmani, Jones, and Patricola, “Interacting Implications of Climate Change,” 4.

[211] Sjoukje Y. Philip et al., “Rapid Attribution Analysis of the Extraordinary Heat Wave on the Pacific Coast of the U.S. and Canada in June 2021,” *Earth System Dynamics* 13, no. 4 (2022): 1697, https://doi.org/10.5194/esd-13-1689-2022.

impacts, including 33 deaths in King County.[212] Thompson et al. considered the 2021 extreme heat event to be one of "the most extreme climate events ever recorded globally."[213] Other research has found that the 2021 Pacific Northwest heat wave "was found to be virtually impossible without human-caused climate change."[214] This finding underscores the rarity of the event in the geographic location in which it occurred.

The 2021 extreme heat event in the Pacific Northwest occurred in a climate around 1.2ºC above the pre-industrial temperature baseline.[215] Although extreme heat events have been historically rare, they are expected to become far more common in the Seattle area in the future due to warming global temperatures. For example, in a +2.0ºC climate, the 2021 extreme heat event would occur every 5 to 10 years instead of every 1,000 years.[216] This change underscores the significant increase in expected impacts by the heat itself but does not consider the compounding impacts that often occur side-by-side with the heat hazard.

Temperatures above 90ºF occur approximately two days in a given year in Seattle at present global temperatures.[217] In a warming scenario of +1.5ºC, this number will increase to approximately three days yearly.[218] These statistically significant increases in maximum temperatures start to appear across a wide area of the western United States in a +1.5ºC world, while conclusions remain mixed farther east.[219] In a warming scenario of +2.0ºC, the number of 90ºF temperatures will increase to approximately six days yearly.[220] In a warming scenario of +2.5ºC, this number will increase to approximately 15 days

[212] Seattle and King County Public Health, "Extreme Heat Response Plan" (Seattle, WA: Seattle and King County Public Health, June 23, 2023), 5.

[213] Vikki Thompson et al., "The 2021 Western North America Heat Wave among the Most Extreme Events Ever Recorded Globally," *Science Advances* 8, no. 18 (May 4, 2022): 1–10, https://doi.org/10.1126/sciadv.abm6860.

[214] Philip et al., "Rapid Attribution Analysis of the Extraordinary Heat Wave," 1690.

[215] Philip et al., 1699.

[216] Philip et al., 1707.

[217] "King County – Seattle, WA," The Climate Explorer, accessed May 4, 2024, https://crt-climate-explorer.nemac.org/.

[218] The Climate Explorer.

[219] Wobus et al., "Reframing Future Risks of Extreme Heat," 1326.

[220] The Climate Explorer, "King County – Seattle, WA."

yearly.[221] This change demonstrates that although extreme heat is still relatively rare in the coastal Pacific Northwest, the prevalence of extreme heat events will increase as the global climate continues to warm.

Extreme heat and drought events are closely linked in the western United States. One reason for this link is the feedback loop, where hot temperatures lead to more evaporation from the soil.[222] The 2021 extreme heat event occurred during a regional drought, which increased the severity of the heatwave and made the event between 2ºF and 4ºF hotter than it otherwise would have been.[223] This feedback loop further intensified the loop to create even drier conditions. These compound events will be much more common in the future, more severe, and longer lasting in western North America.[224] This feedback loop also increases wildfire danger, especially in the western United States.

Extreme heat is a common trigger for wildfire ignition, as vegetation can dry out during such events quickly. The 2021 wildfire season was one of the worst recorded, with numerous resource shortages of fire management personnel and equipment, partially due to the extreme heat event.[225] One groundbreaking study concluded that the influence of the 2021 Pacific Northwest extreme heat event accounted for 21–34 percent of the total area burned in wildfires that year.[226] In addition, the wildfires lasted 59 percent longer and were 34 percent larger than the event would have been without the influence of climate change.[227] The compound heat, drought, and heatwave events will require additional planning in future climate scenarios, as both the frequency and severity of these events will change.

221 The Climate Explorer.

222 Philip et al., "Rapid Attribution Analysis of the Extraordinary Heat Wave," 1704–6.

223 Crimmins et al., *Fifth National Climate Assessment*, 18.

224 Tripathy et al., "Climate Change Will Accelerate the High-End Risk," 3.

225 Piyush Jain et al., "Record-Breaking Fire Weather in North America in 2021 Was Initiated by the Pacific Northwest Heat Dome," *Communications Earth & Environment* 5, no. 1 (2024): 6, https://doi.org/10.1038/s43247-024-01346-2.

226 Jain et al., 1.

227 Jain et al., 1.

Although wildfires bring an immediate risk to public safety after extreme heat events, wildfire smoke leaves a greater impact on a larger number of people over a much wider area. Wildfire smoke exposure has increased by 250 percent since the mid-2000s in the western United States.[228] Human health has suffered as a result, with respiratory hospitalizations increasing by 7 percent due to smoke inhalation over a six-year period.[229] Wildfire smoke is one of the primary cascading health-related impacts from extreme heat events, as studies from Washington show a 35 percent increase in the odds of respiratory mortality for middle-aged and older adults in the days following wildfire smoke exposure.[230] Increasing wildfire smoke will worsen the burden on healthcare facilities in the days following extreme heat events, even after the weather cools.

Compared to hotter climates, extreme heat mitigation measures are not as common in the Seattle area, although some efforts have been made to lessen the impact of these events on the community. The state of Washington has an *Integrated Climate Response Strategy* to outline actions that can be taken to improve the well-being of communities impacted by climate change and extreme heat.[231] As of early 2024, Seattle was actively writing a heat response plan for the specific hazard of extreme heat events.[232] Seattle and King County also have a joint *Extreme Heat Response Plan* administered through the public health department. However, it only includes how agencies will coordinate during such an event rather than tactical mitigation measures.[233] This demonstrates active

[228] Marshall Burke et al., "The Changing Risk and Burden of Wildfire in the United States," *Proceedings of the National Academy of Sciences* 118, no. 2 (2021): 3, https://doi.org/10.1073/pnas.2011048118.

[229] Zhao Liu et al., "Global and Regional Changes in Exposure to Extreme Heat and the Relative Contributions of Climate and Population Change," *Scientific Reports* 7, no. 1 (2017): 7, https://doi.org/10.1038/srep43909.

[230] Annie Doubleday et al., "Mortality Associated with Wildfire Smoke Exposure in Washington State, 2006–2017: A Case-Crossover Study," *Environmental Health* 19, no. 1 (2020): 1, https://doi.org/10.1186/s12940-020-0559-2.

[231] Zachary Kearl and Jason Vogel, "Urban Extreme Heat, Climate Change, and Saving Lives: Lessons from Washington State," *Urban Climate* 47 (2023): 4, https://doi.org/10.1016/j.uclim.2022.101392.

[232] Kimutis, Wall, and Darrow, "Emergency Management Short Term Response," 6.

[233] Seattle and King County Public Health, "Extreme Heat Response Plan."

planning efforts, although many cities with greater heat hazards have more robust infrastructure in place to prepare and plan for extreme heat events.

Individuals within the city of Seattle have made significant changes in some types of mitigation measures. Over the past two decades, air-conditioned households have significantly increased. Despite the recent increases, Seattle remains one of the urban areas with the fewest number of air-conditioned residences. Only 10 percent of Seattle households had air conditioning in 2010.[234] This number increased to 34 percent in 2015 and 53 percent in 2021.[235] The increased prevalence demonstrates a significant uptick in personal mitigation measures to combat both extreme heat and wildfire smoke. However, this incidence also could leave the region more vulnerable in other ways, such as reliance on such systems in the event of a power outage and increased energy consumption.

Despite advances in air conditioning prevalence recently, the population of Seattle continues to be at increased risk during extreme heat events. One reason for this is that King County has the third-highest unhoused population in the United States.[236] Higher numbers of homeless individuals increase the number of negative health outcomes during extreme heat events within the community due to exposure.[237] In addition, demographic changes in Washington state mean that the number of older adults and residents with comorbidities will increase in the coming decades.[238] Even populations not as vulnerable to the negative health consequences of extreme heat are not accustomed to heat events, considering the city's geography near the Pacific Ocean, which acts to moderate temperatures most of the time. Therefore, increasing health risks to the population of Seattle will be exacerbated by future extreme heat and cascading impacts from smoke.

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[234] J. Elizabeth Jackson et al., "Public Health Impacts of Climate Change in Washington State: Projected Mortality Risks Due to Heat Events and Air Pollution," *Climatic Change* 102, no. 1–2 (September 2010): 363, https://doi.org/10.1007/s10584-010-9852-3.

[235] "Sweltering Summers Sending Seattle into Arms of Air Conditioning," Clean Fuel Washington, August 11, 2023, https://www.cleanfuelwa.com/hotter-days-means-more-ac.

[236] Tanya de Sousa et al., "The 2023 Annual Homelessness Assessment Report (AHAR to Congress) Part 1: Point-In-Time Estimates of Homelessness, December 2023" (Washington, DC: U.S. Department of Housing and Urban Development, December 2023), 20.

[237] Kearl and Vogel, "Urban Extreme Heat, Climate Change, and Saving Lives," 6.

[238] Kearl and Vogel, 4–5.

The safety of outdoor workers is less of a concern than in most areas in the United States due to the infrequent nature of extreme heat events and the relatively low numbers of outdoor workers in the Seattle metropolitan area. Under 25 percent of workers in King County work outdoors, which limits the exposure of these workers to extreme heat.[239] In addition, unlike most other states, Washington has enforceable protective laws for outdoor workers during heat events.[240] These considerations suggest emergency managers should be focused on supporting more vulnerable and disadvantaged communities compared to the general population during extreme heat events.

Emergency management professionals can expect the following impacts aligned with FEMA's community lifelines during a typical extreme heat event in these three climate scenarios.

1. Safety and Security

Future extreme heat events will impact safety and security, as first responders will have to take precautions to avoid negative health outcomes while working outside. However, this threat is expected to remain relatively small compared to other locations across the United States in +1.5ºC and +2.0ºC climates. On rare occasions, an increase in heat-related emergency calls will increase demands on first responders, including firefighters, law enforcement, and health workers on the front lines. The larger threat in future climate scenarios will likely relate to extreme heat's contribution to cascading impacts across the Pacific Northwest, especially wildfires. The wildfires resulting from extreme heat events will likely stretch resource capabilities and require more emergency management capacity to devote to wildfires in the future.

2. Food, Hydration, and Shelter

Seattle's water supply is robust, with enough capacity to fully meet demand during normal operations. By 2080, Seattle is still expected to have a 99 percent water system reliability at the current demand. When the demand increases by 10 percent, reliability is

239 Dahl and Licker, *Too Hot to Work*, 5.

240 Dahl and Licker, 3.

still at 98 percent in 2080.[241] However, increased demand for water could stretch the need for water resources in extreme heat events in the future if water usage spikes more significantly. This situation could lead to temporary shortages, although widespread water shortages are not anticipated in a +1.5ºC, +2.0ºC, or +2.5ºC climate. Although Seattle's water supply seems secure, many communities in the Pacific Northwest are much more insecure. Therefore, water availability and reliability considerations must be considered when planning for future extreme heat events in some areas.

Seattle has cooling centers and shelters open during extreme heat events, although individual locations are not published in the city/county Extreme Heat Response Plan.[242] The lack of awareness of shelter locations can be problematic because vulnerable individuals may not know where the shelters are located or when they are open. During the historic 2021 extreme heat event, the city of Seattle opened 36 cooling centers in senior centers, libraries, and community centers.[243] Although these cooling centers can protect some vulnerable residents, many were only open for portions of the day due to lack of resources, staffing, and use.[244] Increased collaboration among agencies to communicate and provide resources to such initiatives, coordinated by emergency management, may alleviate some of these issues in the future.

In a +1.5ºC, +2.0ºC, and +2.5ºC world, extreme heat events may mean an increased need to shelter individuals for a longer period as extreme heat events become more prevalent and last longer. The need for additional sheltering options may be required, especially considering the expected increase in vulnerable individuals and the population overall. Emergency managers will have to work with shelter providers to ensure this

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241 Julie A. Vano et al., "Climate Change Impacts on Water Management in the Puget Sound Region, Washington, USA," in *Washington Climate Change Impacts Assessment*, ed. M. McGuire Elsner, J. Littell, and L. Whitely Binder (Seattle, WA: Climate Impacts Group, 2009), 124, https://doi.org/10.6069/GWSP-MB82.

242 Seattle and King County Public Health, "Extreme Heat Response Plan."

243 Kamaria Hightower, "Staying Cool in Extreme Heat," Office of the Mayor, June 24, 2021, https://durkan.seattle.gov/2021/06/city-of-seattle-opens-additional-cooling-centers-and-updated-guidance-for-staying-cool-in-extreme-heat /.

244 Neil Singh Bedi et al., "The Role of Cooling Centers in Protecting Vulnerable Individuals from Extreme Heat," *Epidemiology* 33, no. 5 (September 2022): 611–15, https://doi.org/10.1097/EDE.0000000000001503.

capacity is available in the future, all while considering the interrelated community lifelines that support a shelter, such as energy, health and medical, and safety and security.

3. Health and Medical

Historically, the health and medical lifeline has seen minimal impacts in Seattle due to extreme heat. In the past 50 years, Seattle has only averaged three to four heat-related deaths per summer.[245] In some unusually hot years, up to 50 or 60 deaths can be attributed to heat.[246] Without additional context, it would seem there is little threat to the health and safety of an average resident.

In reality, Seattle is one of the most sensitive cities to extreme heat events due to a lack of mitigation (such as air conditioning) and the lack of acclimation to extreme heat. In fact, adverse health effects start at just 78.6ºF, which is several degrees lower than most other cities in the United States.[247] One study found a statistically significant increase in King County hospital admissions by approximately 1.59 percent for each degree increase in heat index above 86ºF, demonstrating the potential medical burden from extreme heat events is quite high overall.[248]

Since only 53 percent of residents have air conditioning, extreme heat can still have negative health effects for many residents who do not have air conditioning. Electric fans can help during some heat events, but fan usage will increase heat stress and dehydration for an average adult when the air temperature is over 99ºF.[249] The resulting increase in heat stress limits the efficacy of fans as a potential mitigation measure to combat extreme heat health impacts.

245 "Excessive Heat," Emergency Management, accessed May 18, 2024, https://www.seattle.gov/emergency-management/hazards/excessive-heat.

246 City of Seattle.

247 Seattle Office of Emergency Management, "9.1: Excessive Heat Events," in *Seattle Hazard Identification and Vulnerability Analysis* (Seattle, WA: Seattle Office of Emergency Management, 2019), 9–5, https://www.seattle.gov/documents/Departments/Emergency/PlansOEM/SHIVA/SHIVAv7.0.1.pdf.

248 Tania Busch Isaksen et al., "Increased Hospital Admissions Associated with Extreme-Heat Exposure in King County, Washington, 1990–2010," *Reviews on Environmental Health* 30, no. 1 (2015): 1, https://doi.org/10.1515/reveh-2014-0050.

249 Jay et al., "Reducing the Health Effects of Hot Weather," 715–16.

In future extreme heat scenarios, elderly populations are most at risk of extreme heat. The elderly population is expected to see the largest number of projected excess deaths in the Seattle area during future extreme heat events, with 148 more people dying in a +2.0ºC climate and 266 more people dying in a +2.5ºC climate.[250] This projected fatality increase demonstrates the need for emergency managers to consider a fatality management plan for extreme heat events.

Cascading health impacts are also expected to be felt immediately after future extreme heat events in the Seattle area. Since wildfire prevalence is expected to become more common in the western United States, wildfire smoke is also expected to increase negative health outcomes and hospital admissions immediately after extreme heat-fueled wildfires are sparked. One study showed a six-day lag in wildfire-fueled smoke events after extreme heat occurrences.[251] As extreme heat events occur more frequently—and just as importantly, last longer—the probability of overlapping events increases. This situation could also lead to a further increase in pulmonary conditions in the future.

Overall, emergency managers in a climate like Seattle must know about the health impacts during and after extreme heat events to minimize negative health outcomes and be ready to assist primary care facilities with potential resource needs during extreme heat events.

4. Energy (Power and Fuel)

Seattle City Light, the city's main electricity supplier, relies on hydroelectric power for 91 percent of its supply.[252] Although extreme heat events will not necessarily affect hydroelectric power unless an ongoing drought happens, the increase in electricity demand from air conditioners may exceed the capacity needed to avoid brownouts. This limitation is especially important, considering hydroelectric power capacity is inherently limited to

[250] Jackson et al., "Public Health Impacts of Climate Change," 1–28.

[251] Rosenthal et al., "Population Co-Exposure to Extreme Heat," 6.

[252] Mary Xiao, "Planning for Climate Change in Seattle: Exploring Energy Infrastructure through Scenario Planning" (master's thesis, University of Washington, 2019), 46, http://hdl.handle.net/1773/44464.

the flow of the water. Seattle City Light reports extreme heat events in 2009 and 2015 had negligible impacts on its operations but that "the system's sensitivity to more extreme hot days need [s] to be assessed."[253] While hydroelectric energy may be secure during most future extreme heat events, transmission is more threatened.

Extreme heat's connection to wildfire is more worrisome for electric distribution in the Seattle area. Most of Seattle City Light's distribution and transmission facilities are in forested areas.[254] However, wildfires are historically less frequent in locations where City Light's generation and distribution area lies.[255] However, local wildfire threat will likely climb dramatically as global temperatures rise and drought becomes more frequent.[256] Resulting power outages could cause cascading impacts to other critical lifelines, such as health and medical, if air conditioning and other cooling measures no longer function because of a power outage. With these cascading impacts, emergency managers must prepare for future power disruptions and include them in all aspects of their future planning.

5. Communications

Communications is not expected to be impacted by extreme heat events in Seattle. Although high temperatures could have a negative impact on some communications equipment, this risk is not expected to be widespread. However, since most communications equipment relies on stable electricity, this interconnection ensures communications systems remain functional during extreme heat events. As with many of the other sectors listed in the FEMA lifelines, outdoor personnel may be at risk for heat-related illnesses. The number of communications sector employees is smaller, and much of their work can be accomplished in a climate-controlled location, which limits the threat overall.

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[253] Crystal Raymond, *Seattle City Light Climate Change Vulnerability Assessment and Adaptation Plan* (Seattle, WA: Seattle City Light, 2015), 28, https://www.seattle.gov/documents/Departments/CityLight/ClimateChangeAdaptationPlan.pdf.

[254] Xiao, "Planning for Climate Change in Seattle," 40.

[255] Raymond, *Seattle City Light Climate Change*, 47.

[256] Raymond, 47.

6. Transportation

Extreme heat will affect the transportation lifeline in Seattle, especially in areas away from the marine influence of the Pacific Ocean. Fortunately, many outdoor-intensive transportation industries, such as airports and seaports, lie near the water, and are therefore less susceptible to extreme heat.

The transportation lifeline is not expected to see major impacts from extreme heat events in the city of Seattle under present conditions or in a +1.5ºC, +2.0ºC, or +2.5ºC world. Although high temperatures could have a negative health impact on personnel working in the transportation industry, extreme heat risk is expected to be relatively rare and infrequent. In addition, since Washington has enforceable protective laws in place for outdoor workers during heat events, emergency managers can focus on other lifelines when preparing for extreme heat events in the future.[257]

7. Hazardous Materials

The hazardous materials lifeline is not expected to be impacted by extreme heat events in Seattle under present conditions or in a +1.5ºC, +2.0ºC, or +2.5ºC world. Although high temperatures could have a negative health impact on personnel handling this type of material outdoors, this risk is not expected to be widespread to the material itself.

8. Water Systems

The water system lifeline is closely related to the food, water, and shelter community lifeline mentioned earlier in the scenario. The expected impact on water and wastewater distribution systems is minimal if enough water enters that system to be treated. Studies show the Seattle water distribution system and water supply reliability will remain above 98 percent through 2080, absent significant increased demand.[258] Water system demands are not expected to change during extreme heat events in warming scenarios of

[257] Dahl and Licker, *Too Hot to Work*, 3.

[258] Vano et al., "Climate Change Impacts on Water Management," 1.

+1.5ºC, +2.0ºC, or +2.5ºC, as long as other vital lifelines (such as power) remain functioning.

B. SUMMARY

In summary, Seattle will see more frequent extreme heat events in future climate scenarios. However, this impact is most acutely seen in +2.0ºC and +2.5ºC scenarios. Extreme heat events, like the Pacific Northwest heatwave of 2021, will likely remain relatively rare events in the coming decades. However, extreme heat events in the Pacific Northwest are examples of low-probability/high-impact events. One of the most critical vulnerabilities in Seattle is the lack of overall acclimation due to the normally temperate climate. In addition, cascading impacts such as power losses will be seen across multiple sectors, including water, transportation, and communications. Additional cascading events, such as drought or wildfire spurred by extreme heat events, are a more likely scenario and should be planned for. Despite having a lower extreme heat risk relative to most of the United States, additional planning efforts should be instituted in Seattle that consider these cascading impacts to mitigate vulnerabilities and create a more resilient community.

VII. ANALYSIS

This thesis outlined extreme heat impacts in four major cities within the United States in three future climate scenarios of +1.5ºC, +2.0ºC, and +2.5ºC of warming and paired these scenarios with FEMA lifelines to identify impacts on the emergency management community. The scenarios focused on the cities of Phoenix, Chicago, Atlanta, and Seattle, which represent a large cross-section of climate types and geography that are representative of the United States as a whole. Although these four cities represent distinct climates, some effects of extreme heat events can be extrapolated to analyze a much larger geography of the United States. The resulting scenario analysis demonstrates the effects that extreme heat events will bring to emergency management professionals in the future.

The Phoenix scenario involved a city in a consistently hot—yet dry—environment with robust heat preparedness at the local level. Despite being well prepared, the city has limited cooling center capacity and struggles with water security. The Atlanta scenario involved a moderately hot climate, but with the additional factor of moisture, which increases overall heat stress. Both Phoenix and Atlanta rely heavily on air conditioning for the safety of residents. The Chicago scenario showed a temperate city, with infrequent extreme heat events that involve a combination of heat and humidity. The city is prepared from a planning perspective, yet negative public health outcomes are more common during extreme heat events due to the community being more vulnerable and some residents lacking air conditioning. The Seattle scenario demonstrated the impact of a rare extreme heat event on a city with little air conditioning. Both Seattle and Chicago are unacclimated to the heat, yet regional temperatures are climbing at a pace faster than the global average temperatures that this thesis focuses on. These dynamics lead to varying challenges for emergency managers, depending on their geography and their communities at large.

In all scenarios, extreme heat poses a current risk to communities and infrastructure. In many cases, these threats are increasing significantly as global temperatures warm. Table 1 briefly summarizes extreme heat impacts on each FEMA community lifeline for the four cities mentioned in the scenarios. Extreme heat impacts affected each FEMA community lifeline differently. Table 1 shows consistent risks across many of the community lifelines, while others—such as health and medical and water—show large variations depending on geography. This variation suggests locations where emergency managers can focus while addressing and assessing potential mitigation measures.

Table 1. Expected Impacts on Community Lifelines During Future Extreme Heat Events, by City

Community Lifeline	Phoenix	Chicago	Atlanta	Seattle
Safety and Security	Increased demand for first responders, increased need for safety precautions	Increased number of emergency calls correlated with extreme heat, increased demand on first responders	Increased risk for first responders and other outdoor workers due to consistently high heat and humidity	Increased number of emergency calls correlated with extreme heat, increased demand on first responders
Food, Hydration, and Shelter	High demand for water could lead to shortages, increased sheltering needs	Robust network of cooling shelters, but power failures bring risk	Increasing demand for cooling centers in future climates	Sheltering needs will grow, may need to consider cascading wildfire and smoke impacts
Health and Medical	Elevated threats for heat-related illnesses for increasingly vulnerable populations	High public health impacts to an unacclimatized population, especially for the vulnerable	Elevated threats for heat-related illnesses for increasingly vulnerable populations	High public health impacts on unacclimatized population during infrequent events, especially for the vulnerable
Energy	Potential for power grid failures during extreme heat due to demand on air conditioning	Older infrastructure more prone to failure during extreme heat	Potential for power grid failures during extreme heat due to high energy demand	Potential for some energy disruption from wildfires or other cascading events related to extreme heat
Communications	Generally resilient but dependent on power systems	Generally resilient but dependent on power systems	Generally resilient but dependent on power systems	Generally resilient but dependent on power systems
Transportation	Potential health impact to outdoor workers in transportation industry	Impacts to infrastructure not built to withstand extreme heat events	Potential health impact on outdoor workers in industry	Impacts to infrastructure not built to withstand extreme heat events
Hazardous Materials	Minimal direct impacts	Minimal direct impacts	Minimal direct impacts	Minimal direct impacts
Water Systems	Increased water system demand during extreme heat with limited supply	Increased water system demand during extreme heat with ample supply	Increased water system demand during extreme heat	Increased water system demand during extreme heat

Interdependencies and cascading impacts of critical infrastructure failure have been discussed at length in scenarios within this thesis. Although many of the dependencies are well documented and present outside of the context of extreme heat, the reliance on a few key lifelines may cause a cascading negative impact upon failure during an extreme heat event. Figure 11 demonstrates the interconnections between lifelines, where the line points toward a relied-upon lifeline.

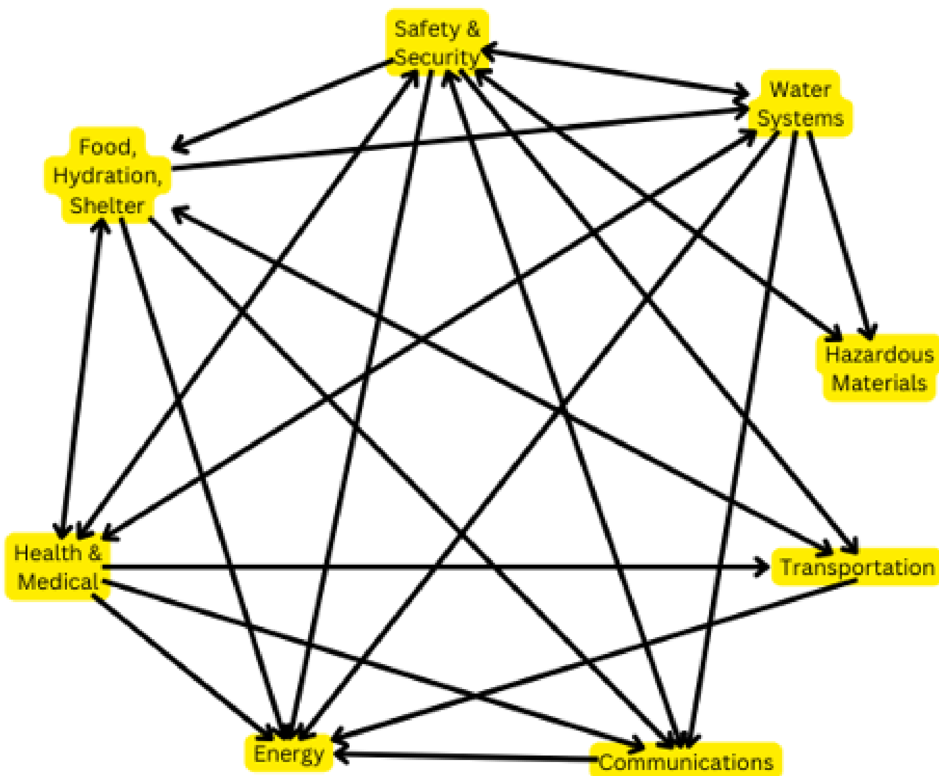

Figure 11. Major Interconnections between Community Lifelines in an Extreme Heat Scenario

This analysis confirms the importance of the energy lifeline as one of the biggest potential sources of failure during an extreme heat event due to the reliance on almost every other sector. Figure 11 further critiques the belief that extreme heat is solely a public health issue and demonstrates the need for a cohesive response in the public sector to mitigate the effects of extreme heat events.

Figure 12 further demonstrates the critical links between the energy lifeline and water systems, which other lifelines heavily rely on to function appropriately. This figure highlights the primary importance of the energy lifeline, followed by the importance of water systems, as all other lifelines rely on their proper function. These key critical infrastructure elements must be accounted for in extreme heat planning and mitigation measures.

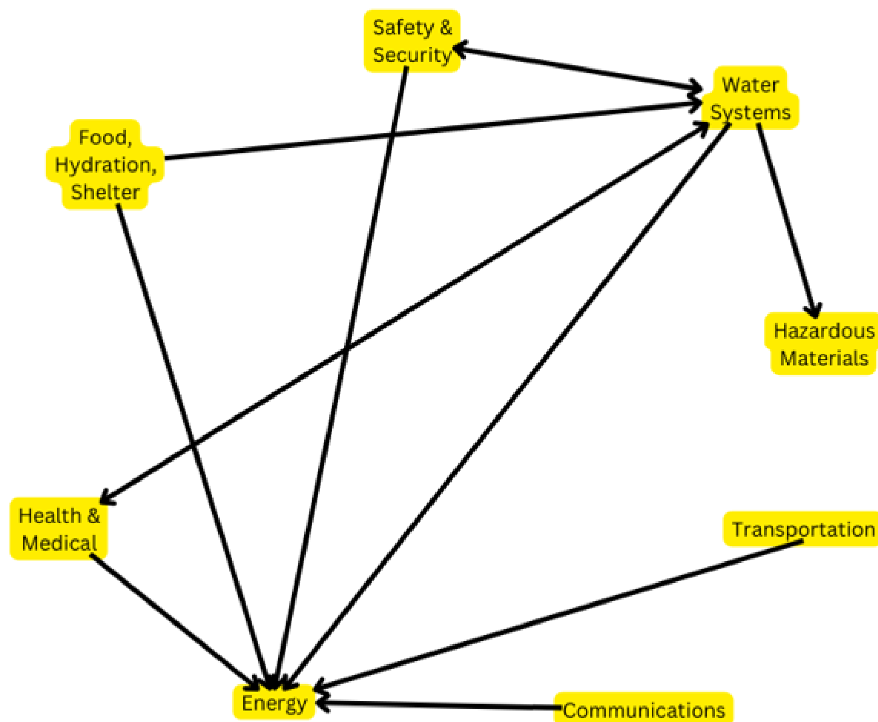

Figure 12. Major Interconnections between the Energy and Water Systems Lifelines

A. ANALYSIS BY COMMUNITY LIFELINES

Based on the research highlighted within the scenario chapters, the author used conclusions drawn from the scenarios to assess future risk for each community lifeline within each scenario city, as shown in Table 2. Risk is commonly defined as the factor of a negative consequence and the likelihood of that consequence occurring. These risks are categorized by impacts on each lifeline in each of the four cities using a three-tiered color system that varies by risk level: green, yellow, and red. This simple qualitative tier system will allow emergency managers to understand future extreme heat risks in an intuitive, consistent, and easily understandable way to improve communication. Green indicates a minimal risk to the integrity of the lifeline in future climate scenarios, meaning that the impact on the sector is expected to be low or not result in significant cascading consequences across other sectors. Yellow indicates a moderate risk of seeing widespread impacts on the sector with more widespread consequences that affect other sectors and a wider population. The yellow risk indicates a higher likelihood of cascading impacts and emergency management involvement during the extreme heat event. Red indicates a high risk, where significant or crippling impacts may be experienced, along with the potential for significant cascading events that affect multiple lifelines. This level of risk will have the highest emergency management involvement due to the potential threats to health and safety in the community. Although several lifelines will experience similar effects across all four of the cities analyzed, notable differences do exist, depending on sector and geography.

Table 2. Assessed Risk for Each Community Lifeline During Extreme Heat Events

Community Lifeline	**Phoenix**	**Chicago**	**Atlanta**	**Seattle**
Safety and Security				
Food, Hydration, and Shelter				
Health and Medical				
Energy				
Communications				
Transportation				
Hazardous Materials				
Water Systems				

The safety and security lifeline showed consistent impacts on first responders, as much of the work that the first responder community does is in an exposed outdoor environment. In addition, extreme heat events will lead to more calls for service and an increased number of dispatches during future extreme heat events. This correlation can be seen especially in areas where extreme heat is less frequent, such as Chicago and Seattle. Additionally, increased fatigue from heat and workload may lead to the need for more first responders during future extreme heat events to ensure the safety of the first responder as well as the community at large.

The food, hydration, and shelter community lifeline demonstrated varying impacts by sector and geography during extreme heat events. Major cities experience relatively minor effects on food availability and production because much of the food grows elsewhere. However, extreme heat events can decrease crop yield in much of the central and southern United States and may lead to shortages of some specific foods after an extreme heat event.[259] This decrease in crop yield is not likely to play a major role in an emergency management response because the food supply, in general, can likely handle these short-term impacts. Hydration is a larger concern, as one of the chief heat mitigation measures to ensure public health is to stay hydrated.[260] Future extreme heat events will require careful consideration and planning by emergency management staff to ensure that water is readily available, especially in the event of a cascading impact that would disrupt water distribution. Sheltering, in the form of cooling centers, will become increasingly important during future extreme heat events. The importance is especially seen in areas without widespread adoption of air conditioning and other cooling measures. Significant disparities distinguish municipalities with respect to sheltering during extreme heat events, with hot cities, such as Phoenix and Atlanta, offering few opportunities for citizens. In addition, many other barriers exist to utilizing shelters, including limited transportation, community stigma, and limited opening hours.[261] Shelters and cooling centers should remain a key mitigation measure for emergency management staff to consider, with the caveat that the centers are not a complete panacea and must be supported with public outreach and logistics. Although the efforts included within the food, hydration, and shelter community lifeline are wide-ranging, hydration and sheltering are vital to maintaining the health and medical lifeline.

259 Intergovernmental Panel on Climate Change, *IPCC, 2023*, 76.

260 Cleveland Clinic, “Hyperthermia.”

261 Bedi et al., “The Role of Cooling Centers,” 2–5.

The health and medical lifeline is the most important consideration for emergency managers and considered the most important lifeline during extreme heat events. Research emphasizes the significant danger that future extreme heat events will have on this lifeline, with some authors suggesting some parts of the globe may become unlivable in future climates.[262] Although those possibilities are beyond the scope of the scenarios contained within this thesis in the United States, all four scenario cities will see an increase in heat-related illnesses and fatalities during heatwaves in a +1.5ºC, +2.0ºC, and +2.5ºC climate, barring significant mitigation measures to lower the risk. Seattle and Chicago are not used to extreme heat events as often as southern cities, which can lead to negative health outcomes as the body is unacclimatized to the heat.[263] The health and medical lifeline has the potential to be taxed in Chicago specifically, as the combination of socially vulnerable communities more prone to negative health impacts, as well as the lower prevalence or use of air conditioning, can lead to negative health outcomes more readily. While Phoenix and Atlanta see hot weather much more often, nearly ubiquitous air conditioning lowers the threat of negative outcomes overall. One obvious exception is outdoor workers and homeless individuals, who see a significant risk in these environments to negative health impacts. Across all four scenario cities, the health and medical lifeline will increasingly be negatively affected in future climates.

The energy lifeline will likely see an increased risk across all scenarios in extreme heat events, partially due to the event itself, along with meta-trends suggesting increasing power demands in the United States amid more limited power generation capacities.[264] The power grid, in general, is one of the main drivers of cascading impacts in the event of a failure. Table 3 shows the expected impacts if the power grid is disrupted during future extreme heat events, using the same risk assessment methodology as Table 2.

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262 Coffel, Horton, and Sherbinin, "Temperature and Humidity Based Projections," 4–7; Li, Yuan, and Kopp, "Escalating Global Exposure," 1; Samuel Lüthi et al., "Rapid Increase in the Risk of Heat-Related Mortality," *Nature Communications* 14, no. 1 (2023): 1–5, https://doi.org/10.1038/s41467-023-40599-x; and Chak et al., "Mortality Risk of a Future Heat Event," 634–35.

263 Anderson and Bell, "Heat Waves in the United States," 217.

264 Renee, Kumar, and Roshanak, "Managing the Water–Electricity Demand Nexus in a Warming Climate," 241–48.

Table 3. Assessed Risk for Each Community Lifeline During Extreme Heat Events with Prolonged Failure of Power Lifelines

Community Lifeline	Phoenix	Chicago	Atlanta	Seattle
Safety and Security				
Food, Hydration, and Shelter				
Health and Medical				
Energy				
Communications				
Transportation				
Hazardous Materials				
Water Systems				

Table 3 demonstrates a consistently large impact across all scenarios and geographies, with almost every other lifeline showing a significant interdependency due to the reliance on the power grid. All scenarios suggest a potential for a large loss of life.[265] This fact suggests that emergency managers must work closely with power suppliers during extreme heat events and focus mitigation measures on working with power suppliers to address projects that increase redundancies and protect infrastructure. Although physical protection may be a priority in wildfire-prone areas such as Seattle, this protection may also include cybersecurity protection across all geographies to ensure bad actors are less likely to take advantage of extreme heat to maximize the impact on a community.

The communications community lifeline heavily depends on the energy lifeline. Future extreme heat events may impact portions of communications infrastructure, yet these impacts

[265] Stone, Jr. et al., "Compound Climate and Infrastructure Events," 6963.

are expected to be minimal as long as power is maintained. This impact further demonstrates the importance of ensuring a stable power supply during and after an extreme heat event. This importance will continue in all climate scenarios across all geographical scenarios.

The transportation community lifeline will experience disruption from extreme heat events in two ways. The first impact will be a physical impact on highways, roads, railways, and airports. These impacts will be most apparent in cooler climates, such as Chicago and Seattle, where certain infrastructure is not built to withstand extreme heat temperatures as readily as Phoenix. Previous examples of physical impacts include pavement buckling on roads, metal warping on train tracks, and metal expanding to the point where bridges cannot be raised.[266] In addition, cities with aging infrastructure, such as Chicago, may see an increased vulnerability as that infrastructure becomes more prone to failure during extreme events.[267] The second impact of the transportation lifeline will be the negative effect on transportation workers who support a wide array of industries. This impact will be seen across all four cities in future extreme heat scenarios, with Phoenix and Atlanta seeing the most consistent impacts due to the hot climate. Across all scenarios, impacts to the transportation lifeline will likely increase during heatwaves in a +1.5ºC, +2.0ºC, and +2.5ºC climate.

The hazardous material lifeline is perhaps the least prone to the effects of extreme heat, and the relative risk has been assessed as low. Despite interconnections with other lifelines, most facilities and potential contaminants can withstand temperatures well above those expected in a +2.5ºC climate and little peer-reviewed research indicates a link between hazardous materials and extreme heat. Therefore, emergency managers should prioritize sustaining other lifelines in the event of extreme heat affecting their jurisdiction.

The water systems lifeline is critical to maintain during extreme heat events. This community lifeline also carries varying risks depending on the geography. Areas with poor water resources are expected to see an increasing degradation of water security during and after

266 "Extreme Heat," Extreme Weather and Climate Change, accessed June 15, 2024, https://www.cisa.gov/topics/critical-infrastructure-security-and-resilience/extreme-weather-and-climate-change/extreme-heat.

267 Richard G. Little, *Managing the Risk of Aging Infrastructure* (Geneva, Switzerland: International Risk Governance Council, 2012), 6–7.

extreme heat events due to increased consumption, such as Phoenix. Areas with good water resources, such as Chicago, will see a limited impact to this lifeline during an extreme heat event. The importance of maintaining this lifeline can be seen in Table 4. Table 4 demonstrates the interconnected impacts to other community lifelines if the water systems were to fail, using the same risk assessment methodology as Table 2.

Table 4. Assessed Risk for Each Community Lifeline During Extreme Heat Events with Prolonged Failure of Water Lifelines

Community Lifeline	Phoenix	Chicago	Atlanta	Seattle
Safety and Security				
Food, Hydration, and Shelter				
Health and Medical				
Energy				
Communications				
Transportation				
Hazardous Materials				
Water Systems				

Since hydration is an important mitigating factor during extreme heat events, significantly negative outcomes affect multiple sectors, including health and medical. Safety and security also sees a significant risk as personnel and personal safety is severely compromised by the lack of water. Although the energy sector is also impaired, many plants have contingencies in place to mitigate water outages or reuse existing local water supplies to continue plant operations. These impacts suggest that emergency managers should consider water infrastructure when planning for extreme heat events and cascading impacts to those events in all geographies, despite the perceived level of water security.

B. KEY FINDINGS

Extreme heat events share common themes across the four cities included in the scenarios. All cities showed an increasing number of extreme heat events, coupled with increasing severity and longevity of those events. All scenarios showed that extreme heat, like many natural disasters, disproportionately affects vulnerable populations within the community, including people with low incomes, the elderly, and people with certain pre-existing medical conditions. Many other factors varied between cities, including planning efforts for extreme heat events.

Although many findings showed similarities across all four cities, some differences did stand out. For example, the link between extreme heat, drought, and wildfire in Seattle and surrounding regions suggests the need to incorporate emergency management planning for all these factors together.[268] The same can be said for Chicago, where extreme rainfall probabilities increase directly after an extreme heat event.[269] These nuances in meteorological and ecological interdependencies by geography will continue to require individualized threat assessments despite the many similarities.

Increasing planning efforts also correlate with a decrease in negative impacts from past extreme heat events in the community. This effect appears in increased planning and preparation in Chicago following the deadly 1995 event and the more recent 2021 event in Seattle. This organizational response may reflect an availability heuristic, a cognitive bias where the perception of the risk of another event occurring is disproportionately large.[270]

[268] Burke et al., "The Changing Risk and Burden of Wildfire in the United States"; Claudia Vitolo et al., "Mapping Combined Wildfire and Heat Stress Hazards to Improve Evidence-Based Decision Making," *Environment International* 127 (2019): 21–34, https://doi.org/10.1016/j.envint.2019.03.008.

[269] Zhang and Villarini, "Deadly Compound Heat Stress-Flooding Hazard"; Khan, Bhattarai, and Chen, "Elevated Risk of Compound Extreme Precipitation."

[270] Amos Tversky and Daniel Kahneman, "Availability: A Heuristic for Judging Frequency and Probability," *Cognitive Psychology* 5 (1973): 207, https://familyvest.com/wp-content/uploads/2019/02/TverskyKahneman73.pdf.

However, this bias has worked to emergency management's advantage as extreme heat events have become more frequent. The example from the subsequent 1999 Chicago heatwave showing an improvement in the overall response—as well as a decrease in loss of life—is to the benefit of the community.

However, the thesis scenarios also find that the most impactful extreme heat events will be those that affect the energy and water community lifelines. Water is a crucial part of life and is even more important during heat events. Energy supplies are vital to use the number one mitigation measure to improve public health outcomes in a heatwave: air conditioning. Together, ensuring that both community lifelines are functioning appropriately must be crucial pieces of any extreme heat planning process and must be prioritized to ensure community health and safety.

Another key finding is the need for an integrated approach to responding to and managing extreme heat events. Historically, extreme heat was solely thought of as a public health threat. However, as this thesis explains, the resulting impacts of extreme heat events are much broader across multiple sectors. This interconnectedness may suggest needed policy changes to promote more cross-sector collaboration in dealing with extreme heat in the future. Although policymakers have a myriad of pressing issues to fund and prioritize, extreme heat needs attention within that discussion.

Finally, communicating the hazards of extreme heat is vitally important in incorporating a people-first message that resonates with vulnerable populations. Cooling centers will not be effective if the residents who need them refuse to go. The messenger (not just the message) is often important to driving meaningful public engagement. Communicating the threat of extreme heat is no different, and trusted community leaders must carry that message to those at risk.

These key findings are important to understanding the cross-cutting impacts of extreme heat on various geographies and cities. The final chapter will address recommendations and paths forward to mitigate the overall impacts as the climate warms and extreme heat events become more frequent.

VIII. CONCLUSION

This thesis outlined the future impacts of extreme heat events on emergency managers in the United States. The thesis analyzed extreme heat events in four major cities in the United States—Phoenix, Chicago, Atlanta, and Seattle—under three future warming scenarios to accomplish this task. These scenarios included a global temperature increase of +1.5ºC, +2.0ºC, and +2.5ºC, or the expected climates in 2030, 2050, and 2090, respectively, under moderate warming projections. By pairing the scenarios with FEMA lifelines, the study identified the response and recovery implications from extreme heat events for emergency managers and communities.

This chapter provides a comparative analysis and summary of findings, as well as five key recommendations for emergency managers as they look to plan for future extreme heat scenarios.

A. COMPARATIVE ANALYSIS AND FINDINGS

All four scenario cities will likely see an increasing number of extreme heat events in the future and an increase in event severity in future climates. This increase will more strongly affect temperate cities across the northern tier of the United States, where a combination of fewer mitigation measures (such as air conditioning) and lower acclimatization to hot temperatures exacerbated by more increasingly frequent extreme heat events will have the greatest effect on communities, and therefore emergency managers. Negative consequences for public health will remain the most significant threat resulting from extreme heat events, and the impacts will grow in all three climate scenarios of +1.5ºC, +2.0ºC, and +2.5ºC.

Although all cities face some of the same public health challenges, planners must consider other unique challenges. These considerations should focus on local differences when planning and preparing for extreme heat events. For example, the Seattle scenario must consider the cascading impact of wildfire smoke, whereas the Phoenix scenario may anticipate water supply shortages. In Chicago and Seattle, early season heatwaves have more negative health effects due to the community's lack of acclimatization to extreme temperatures. Transportation and air conditioning access varies widely within Chicago as well, which both correlate to health outcomes in certain areas. These differences emphasize the need for individualized planning efforts tailored to specific geographies and situations.

Although some planning is individualized, planning for cascading events related to extreme heat is imperative. Based on this analysis, the two most important considerations during an extreme heat event will be maintaining electrical power and water service. Although protecting these two lifelines may seem common sense, almost every other critical sector will experience massive disruption if these two sectors fail. The failure could also signify a large loss of life during an extreme heat event. This finding should renew the discussion about protecting critical infrastructure in the United States and the need for closer collaboration between the utility industry and emergency management staff in planning efforts.

B. IMPLICATIONS FOR EMERGENCY MANAGERS

Emergency managers will continue to play a critical role in responding to and recovering from extreme heat events in the future. The profession is already busy but will become even busier in the future when considering an increasing workload from more frequent disasters. Future climates will require the profession to plan for more cascading events unless and until managers can mitigate present-day vulnerabilities in advance.

Although public health professionals have historically been at the forefront of extreme heat response and recovery, the changing climate will require a more interdisciplinary and collaborative approach in the future as potential impacts spread to other sectors. The multi-sector and multi-disciplinary approach is a skillset uniquely suited for emergency managers who work across all levels of government and the private sector. These broad and varied relationships will be crucial during future extreme heat responses in all scenarios.

C. KEY RECOMMENDATIONS

Based on the extreme heat scenarios and cross-cutting comparative analysis within this thesis, the following five recommendations are most important for emergency managers to consider when preparing for future extreme heat events.

1. Prepare for Cascading Impacts

One of the primary findings in this thesis is the widespread risk of cascading events occurring during extreme heat events. These cascading events can range from power grid failures due to the overuse of electricity, to water shortages, to the greater potential for subsequent flooding events in the Midwest in the wake of heat episodes. Extreme heat is a deadly natural disaster but could be much more deadly if other critical support systems fail. Extreme heat preparation and planning must focus on low-risk/high-impact events, which will become the high-risk/high-impact events of the future. This planning includes creating plans that envision these types of cascading events and provide mitigation measures against the worst impacts. The cascading impacts and interdependencies require the careful consideration of each emergency manager and must account for the specific vulnerabilities of each community, dependent on geographies and climate risks.

2. Create Heat-Specific Plans

Although emergency management planning efforts have improved over the years, much of the effort has gone into producing “All Hazards” plans. These plans aim to reduce the need to create a separate document for different hazards or emergencies. One critique of this process is that it rarely includes the necessary detail to respond to an extreme heat event. Many “All Hazards” plans neglect to plan for cascading impacts, especially since extreme heat is a hazard rarely contained within a single community. This spread limits the capability of mutual aid and other support, which are core emergency management concepts addressed in most plans. Plans specific to extreme heat can also include various relevant stakeholders with specific heat-related equities.

These plans should include private-sector utilities and healthcare networks, water-consuming sectors such as irrigation districts, and disadvantaged communities that are sometimes neglected in community engagement processes. Since the impacts of extreme heat are wide-ranging, including this wide net of stakeholders can act as a positive force multiplier by including all interconnected public and private organizations that may be involved during a heat event.

Local, state, and federal agencies will be encouraged to lead the implementation of heat emergency response plans to streamline coordination and resource allocation during extreme heat events. These plans can be scalable and flexible, based on community and the overall threat of extreme heat. By leading the efforts to support outreach to community leaders and officials, FEMA can assist by providing planning resources and sharing best practices with communities as they develop these plans.

3. Focus on Public Health, but Not at the Expense of Other Critical Sectors

Public health remains at the forefront of the extreme heat discussion, as many of the negative consequences directly relate to public health outcomes. This relationship suggests that short-term planning and mitigation should still focus on the health sector. In practice, it could look like increased outreach to vulnerable populations, such as those with cardiovascular or respiratory diseases, as well as socially isolated individuals who may not have transportation to travel to a cooling center. Although the health sector is vital, emergency managers cannot focus on a single sector while ignoring other critical sectors that may have an equally large impact on a community. Contingency planning is crucial in the power and water sectors during extreme heat events, meaning that close collaboration with utilities is crucial when planning, preparing, and mitigating for expected extreme heat impacts in the future. Communicating the need to public and private sector stakeholders to integrate heat resilience considerations into infrastructure planning and system design would minimize the vulnerability of critical assets to extreme heat stress and further build resilience in impacted communities.

4. Improve Heat Awareness and Communications

Every extreme heat death is preventable, yet a combination of factors continues to lead to deaths every year. One recommendation is to incorporate universal standards to warn about extreme heat events in an easy-to-understand way. The recommendation also focuses on urging people-first messaging to reduce the use of scientific jargon and focus on the action an individual should take. Communication requires a trusted messenger to relay the information. The messenger could be a trusted advocate in a socially vulnerable community or a doctor for someone with a condition that makes them more vulnerable to heat. Although these campaigns are currently in place for some jurisdictions, many communities at most significant risk from deadly extreme heat events do not have public awareness campaigns.

This recommendation would proactively support emergency managers and public health professionals with various tools to communicate with the public tailored to specific community groups and needs. These tools can include developing messaging templates that communities can customize, as well as a repository of successful outreach materials that other communities can emulate to reach out to vulnerable communities and socially isolated individuals. Integrated and coordinated messaging by all relevant stakeholders can minimize miscommunication and produce positive results in the form of individuals taking the right precautions during extreme heat events.

5. Advocate for Funding to Address Extreme Heat Mitigation Efforts

Emergency managers at all levels have a limited amount of funding. Although several of these recommendations may seem relatively simple, all require additional resources and, therefore, additional funding. Emergency managers must rely on elected officials and official budgets for this funding, yet public officials often prioritize more pressing needs instead of funding for additional support during extreme heat events. Examples can be seen with limited cooling center hours or conducting limited outreach to at-risk individuals due to constraints in the hours that public buildings are normally open. Emergency managers must continue to improve extreme heat awareness with elected officials to ensure the officials are aware of more frequent and impactful future events and the potential for more staff and monetary resources.

D. FINAL THOUGHTS AND FUTURE RESEARCH

This study focused on four major cities and an urban environment. Although the study cities included four different geographies, urban America is not a monolith. Each city has unique demographics, social structures, and governments, making literal comparisons challenging. These challenges are even seen within cities, as each neighborhood or block may see vastly different effects from the same extreme heat event. Future research could focus on these specific factors to discover potential force multiplier-type effects depending on each city's situation, even if they share similar geographies.

Emergency management planning efforts tend to focus on the short term. Climate change, in general, is a much longer-term threat. This threat is especially true if our current habits continue as a society despite the overall warming trajectory. Although many emergency managers in the profession today will not have to worry about the "what if's" in 2100, it would be beneficial to the long-term planning of communities to consider climate change scenarios exceeding +2.5ºC in the future. Some research suggests that future warming will be more unpredictable as the temperature climb accelerates, which could be worsened by reaching unknown climate tipping points in the future.[271] Therefore, future research could consider higher temperature scenarios when large and widespread impacts of climate change will increase extreme heat threats considerably in the United States.

The threat of extreme heat is not going away. Instead, it is increasing rapidly as the climate changes. Hopefully, decision-makers will consider some of the recommendations within this thesis to increase overall resilience to the hazard. Many of our heat-related vulnerabilities are products of our own creation, such as deteriorating infrastructure, lack of planning, or mismatched emergency management priorities. Yet if vulnerabilities to extreme heat can be seen within the homeland security and emergency management communities, they can also be seen by adversaries looking to inflict maximum damage during a time when the country is most vulnerable. In an increasingly uncertain and insecure world, extreme heat may further exacerbate national security concerns and debunk the thinking that extreme heat is "only a public health threat." In our uncertain world, extreme heat is a national security threat that requires urgent government attention to address.

[271] Wobus et al., "Reframing Future Risks of Extreme Heat"; Coffel, Horton, and Sherbinin, "Temperature and Humidity Based Projections."

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