MAKING CITIES COOL AGAIN:
HAZARD MITIGATION STRATEGIES IN HAZARD MITIGATION PLANS FROM SIX US STATES

By

EMILY WILLIS

Submitted to the graduate degree programs in the School of Architecture, Design and Planning and Graduate Faculty of the University of Kansas in partial fulfillment of the requirements for the degree of

MASTER OF URBAN PLANNING

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Chairperson Ward Lyles

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Stacey Swearingen-White

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Rachel Krause

Date Defended: May 30, 2017

The Thesis Committee for Emily Willis
certifies that this is the approved version of the following thesis:

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Chairperson Ward Lyles

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Abstract

More people in the US are killed per year by heat waves than any other weather-related disaster. Extreme heat events (heat waves) are also expected to increase in severity and frequency due to climate change. Because of the urban heat island effect that causes cities to warm faster than surrounding rural areas, urban areas are at greater risk of experiencing devastating heat waves. By changing the way land is used, cities can reduce the threat of heat waves. There are three categories of land use-related heat wave mitigation strategies: cool materials, greening, and energy efficiency strategies.

I analyzed 47 county hazard mitigation plans to determine if local jurisdictions are using these heat wave mitigation strategies. I found that although most hazard mitigation plans include a section focused on heat hazards, few plans include land use mitigation strategies focused on mitigating heat. Most plans did include land use mitigation strategies used to mitigate other disasters that could have heat wave co-benefits. Population and region had positive relationships with the comprehensiveness of the heat section. None of the variables I tested had associations with the inclusion of heat-related mitigation strategies or co-benefit mitigation strategies.

Keywords: heat waves, extreme heat events, climate adaptation, hazard mitigation plans

Acknowledgments

The guidance of my committee members, help from friends, and support from my family, especially my husband, have made the completion of this thesis a reality.

I would like to thank my advisor, Ward Lyles, for his excellent guidance and continual support throughout the entire process. I appreciated his analogies, his advice on work-life balance, and his understanding of my sometimes-panicky feelings that helped me start my apprenticeship as a scholar. His comments on numerous drafts and revisions were invaluable as I worked through the process of formulating my ideas and my development as a scholar. Without his direction, this research would not have been possible. I am also grateful to my committee members Stacey Swearingen-White and Rachel Krause for agreeing to serve on my committee and being excited about the topic that I chose.

I would like to thank my urban planning friends who sympathized with me despite not doing a thesis. In particular, I would like to thank Erin Hogan for the countless hours spent discussing my thesis. Without our weekly talks, I am not sure I would have finished.

I also must express gratitude for my parents who edited my papers throughout my academic career and taught me how to have a thick skin when receiving documents covered in red ink. But I am especially grateful for their willingness to listen, sympathize, and encourage when I did not have a thick enough skin or felt that I couldn't do anymore.

Finally, I am forever grateful to my husband, Steven. Without him, I do not know how I would have finished this project. Thank you for listening to me complain about statistics and encouraging me when I could not rely on my own strength. And, more than anything else, thank you for supporting me in completing my degree even when it meant living apart for our first year of marriage. You are truly a man among men.

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Chapter 1: Making Cities Cool Again: An Introduction

In 2003, a massive heat wave hit the British Isles and Western Europe (Stone, 2012, pp. 1–12). The heat wave lasted all summer and was the primary cause of death for an estimated 70,000 people, nearly 40,000 in France and Italy combined. The extreme heat event caused an estimated $13 billion in economic losses and inspired the adoption of heat response plans in both European and US cities (Stone, 2012, p. 6; Lowe, Ebi, & Forsberg, 2011, pp. 4624 & 4625). With its catastrophic number of deaths and its soaring price tag, the 2003 European Heat Wave was one of—if not *the*—worst weather-related disaster in a developed nation (Stone, 2012, p. 12).

Heat waves are the deadliest weather-related disasters in modern developed nations yet, most cities were not built to keep people cool (Rojc, 2016). In fact, cities tend to amplify heat hazards due to the urban heat island effect (UHI; "local climate change") that describes how urban areas warm faster than rural areas (Stone, 2012, p. 13). Urban areas must shift the way land is used in order to counteract the UHI and the associated heat waves. Although some of the hazards associated with climate change, such as coastal flooding due to sea level rise, will only impact areas close to the ocean, heat waves will increase in frequency and severity across the US (Melillo, Richmond, and Yohe, 2014). In fact, some researchers have found that the rate of heat waves has already increased in some of the largest cities in the US (Stone, 2007; Habeeb, Vargo, and Stone, 2014).

Many of the response mechanisms we have in place for dealing with heat waves when they arrive—such as using air conditioning or spreading water on heated surfaces (Williams, 2017)—are not sustainable practices. In fact, relying on air conditioning exacerbates heat waves by contributing to climate change through the emission of more greenhouse gases (Schlossberg, 2016). Using air conditioning to cool humans and using water to cool heated surfaces may help reduce the number of deaths from individual extreme heat events, but these strategies do nothing to reduce the threat of heat wave disasters. There are however, heat wave mitigation strategies that can help cool entire cities before a heat wave occurs. Heat wave mitigation is built on the counterintuitive idea that humans can influence the weather. As Stone (2012) stated, "Many do not consider changing the weather in cities to be a viable policy option for managing environmental problems. Yet, it should be" (p. 103).

Stone and other researchers have identified heat wave mitigation strategies that can help change the weather in urban areas by altering the way land is used. Yet these strategies have little efficacy if they are not applied in the urban areas that are experiencing or will experience more heat waves. In the US, local policies concerning hazard mitigation are usually identified in a local government's hazard mitigation plan.

In this thesis, I attempt to assess the state of heat hazard mitigation planning in the interior US. Specifically, I analyze 47 county-level hazard mitigation plans for inclusion of land use-related heat wave mitigation strategies. My research answers the following questions:

- Does a county's climatic region impact the strategies it uses to mitigate heat events? Do other variables impact which heat wave mitigation strategies a county includes in its hazard mitigation plan?
- Does a county's climatic region impact the strategies included in its hazard mitigation plan that could have heat wave mitigation co-benefits? Do other variables impact the types of strategies with co-benefits are included?
- What variables influence the comprehensiveness of a plan's heat section?

In Chapter 2, I outline three reasons it is important to study heat wave mitigation. First, extreme heat caused the deaths of on average 130 people per year between 1986 and

2015 in the US (NWS, 2016). This is more deaths than any other weather-related hazard. Second, the frequency and intensity of heat waves, which are already rising, will only increase due to climate change (Stone, 2007; Stone, 2012). Third, heat waves will continue to impact every part of the country (Melillo, Richomond, and Yohe, 2014). Heat wave mitigation researchers have identified three categories of mitigation strategies that reduce the threat of heat waves through land use. These three categories are cool materials, greening, and energy efficiency strategies (see section 2.1.2.2 for more information on each strategy category). Hazard mitigation plan (HMP) evaluation researchers have found that land use mitigation strategies are uncommon in HMPs (Lyles, Berke, and Smith, 2014a). Using a cross-sectional, multi-state approach, I analyzed county hazard mitigation plans to determine if local governments are aware of the threat of heat hazards and if they are using cool materials, greening, or energy efficiency strategies to mitigate heat hazards.

In Chapter 3, I outline the methods I used to identify the plans to download and to code the data I collected from the plans. I relied on methods previously established by plan quality evaluation and hazard mitigation plan evaluation scholars (Lyles, Berke, and Smith, 2014a; Lyles, Berke, and Smith, 2014b). I decided to use HMPs because most communities have one so that they can remain eligible for federal disaster funding. I developed a three-step process to generate a representative sample of counties from the interior US. First, I determined the climatic regions and the climatic sub-regions. Second, I randomly selected the states from the sub-regions. And finally, I selected the counties based on population (over 100,000 and under 1,000,000). Altogether, I downloaded 47 plans from counties in six states and three climatic regions.

As explained in Chapter 3, I collected three categories of data: county characteristics, plan characteristics, and heat wave data. I started my data collection process by determining if the plan contained a heat section—a section dedicated to defining and explaining heat hazards; if a plan did not contain a heat section, it did not cover heat hazards in depth. Although I was the only coder, I read through each plan three times and updated my data if I found discrepancies. I also developed a ranking system to help me consistently compare the comprehensiveness of heat sections. Using the ranking system, I gave each plan's heat section a score of 0-10. I used descriptive statistics, Pearson's R correlations, ANOVA tests, means tables, and Chi-square tests to analyze my data.

In chapter 4, I describe the results from the statistical tests described in Chapter 3. In Chapter 5, I further discuss these results. I found that most of the plans include a heat section, suggesting that most counties are aware of the threats they face from heat hazards. However, there is a significant difference in the mean heat section ranking between states and regions. This indicates that there is considerable variation in heat section comprehensiveness between counties located in regions traditionally associated with heat waves (such as the humid Midwest) versus those in regions less commonly associated with heat waves (such as the arid Southwest). There is also a positive relationship between heat section ranking and six other variables.

Despite the fact that a majority of plans include a heat section, only five plans include cool materials, greening, or energy efficiency heat wave mitigation strategies. This finding suggests that most local governments have not recognized changing the weather as a "viable policy option" (Stone, 2012, p. 103) for mitigating heat waves. However, 40 plans include cool materials, greening, or energy efficiency strategies used to mitigate non-heat-related hazards such as floods and severe storms. There is no relationship between region or state and any of the heat wave mitigation or co-benefit strategies included in the plans. Out of the eleven variables I tested with the strategies, only drought word count had a significant relationship with the inclusion of greening strategies. This suggests that the sample size was too small to determine relationships or that I did not include the correct variables.

As counties experience more frequent and intense heat waves, land use mitigation strategies such as cool materials, greening, and energy efficiency strategies will become increasingly important. It is important that planners in the interior US are made aware of the types of hazards that will threaten their communities due to climate change. It is equally important that planners are instructed in the best mitigation options for their county, state, and region.

Chapter 2: Heat Waves and Hazard Mitigation Plan Evaluation Literature

This chapter provides an overview of research on heat waves and hazard mitigation plan evaluation. In section 2.1, I define heat waves and why they are a hazard of concern for many communities, including their relationship to climate change and the urban heat island effect. I also identify the three main categories of land use strategies that the heat wave literature indicates can help mitigate heat: cool materials strategies, greening strategies, and energy efficiency strategies. In section 2.2, I define hazard mitigation and proceed to review the literature on plan quality, including hazard mitigation plan quality. Finally, I end the chapter by explaining how my research helps bridge some of the gaps in the current literature.

2.1 Heat Waves

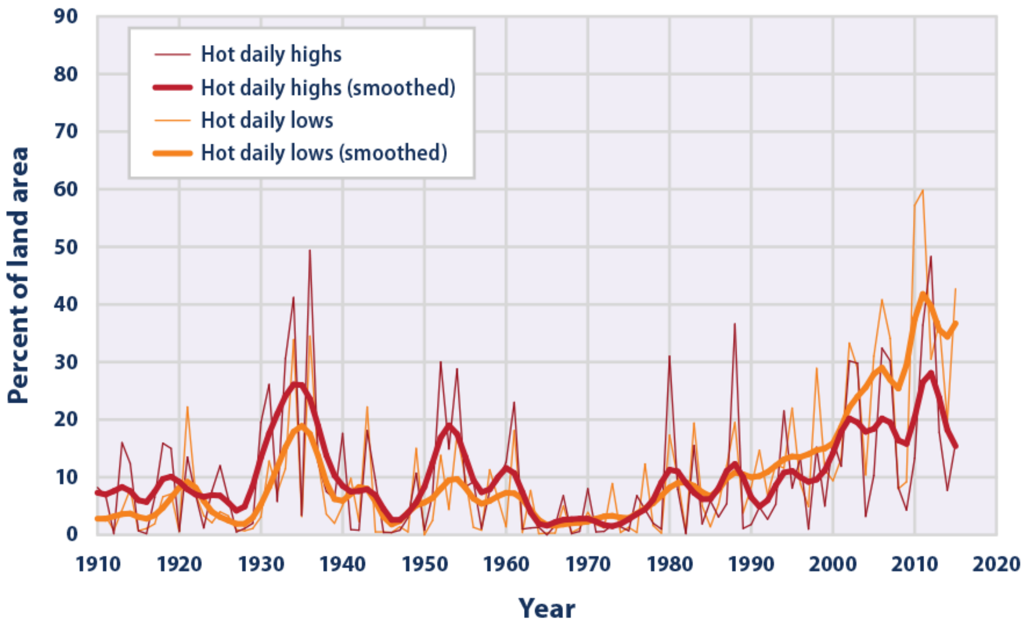
Heat waves are hazards that have the potential to be devastating. They are also hazards that cities can do more to mitigate. In sections 2.1.1 and 2.1.2 I explain what natural hazards and heat waves are, recount the human toll from heat waves, and review the literature on heat wave response plans. I then explain local climate change (the observation that cities are warming faster than the global average) and the literature on land use strategies that cities can use to mitigate heat waves.

2.1.1 Introduction to natural hazards and heat waves. Natural hazards are natural phenomena that threaten human lives and livelihoods (FEMA, n.d.). Some hazards, like earthquakes, have an almost instantaneous onset with no warning while others, like droughts, have a gradual onset. Heat waves lie somewhere in the middle of this onset continuum. Meteorologists and climatologists can provide warnings, but usually only a few days in advance of an event.

A heat wave, also called an extreme heat event (EHE) or excessive heat, is generally understood to be a prolonged period of abnormally high temperatures (EPA, n.d., p. 24). The temperatures that constitute an EHE vary by region. Gaffen and Ross (1998) found that temperatures during an EHE exceed the 85^{th} percentile of the long-term range of temperatures experienced in that region (p. 529). The U.S. Environmental Protection Agency (EPA) classifies a heat wave as lasting at least four days. However, some heat waves last much longer. For example, a heat wave spread across much of the US from March 1 to March 27, 2012 (Hoerling, 2012).

High temperatures are not the only concern during a heat wave. Extreme heat is often exacerbated by water. Paradoxically, both excessive humidity and drought conditions can make heat waves more dangerous. High humidity can be particularly dangerous and is included in the US Heat Index in an effort to have heat warnings reflect how hot the temperature actually feels to a human (NWS, n.d.a). As a result, most US residents seem to associate heat waves with more humid areas (Sheridan, 2006, p. 3), but extreme heat can and does impact all states in the US (Melillo, Richmond, and Yohe, 2014). Records collected by the EPA indicate that temperatures are increasing nationwide, especially at night (figure 2.1; EPA, 2016a). As global and local temperatures continue to rise, climate scientists expect that the frequency and intensity of heat waves will also rise (Habeeb, Vargo, and Stone, 2014). More heat waves also mean more heat related deaths.

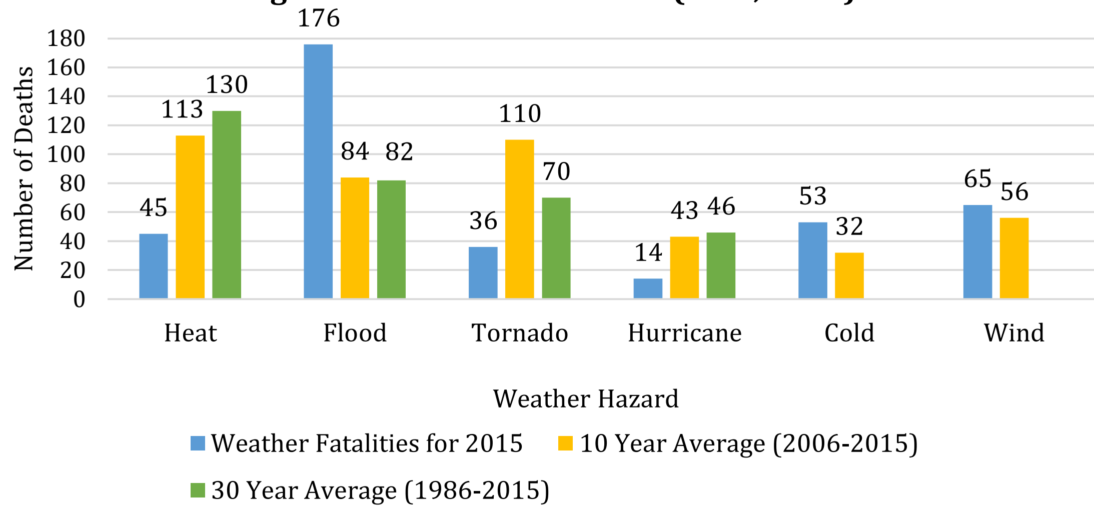
Figure 2.1: Area of the Contiguous 48 States with Unusually Hot Summer Temperatures, 1910-2015 (EPA, 2016a)



2.1.1.1 Heat-related deaths and historic heat waves. The human body is usually adept at removing excess heat through sweating, varying blood circulation, and, eventually, panting (NWS, n.d.b). Extreme heat, however, can tax the body beyond its natural ability to deal with heat, resulting in a heat illness. Heat illnesses increase in severity from heat cramps—which can usually be treated by cooling down and rehydrating the victim—to heat stroke—a serious medical condition that requires proper medical attention and can result in death.

Heat waves do not provide dramatic footage easily used to capture the attention of media outlets and their consumers, unlike hurricanes, floods, and tornadoes (Klinenberg,

Figure 2.2 Weather Fatalities (NWS, 2016)



2002, p. 24; Stone, 2012, p. 2). Yet heat-related complications have been the primary cause of death for over 9,000 people in the US between 1979 and 2014 (EPA, 2016). In fact, heat waves are the most common weather-related killer in the United States (NWS, 2016; figure 2.2). The Chicago, IL, heat wave of July 1995 illustrates how quickly heat can take a toll. The heat wave lasted five days, had a heat index that reached one hundred degrees three days in a row, and was the leading cause of death for an estimated 700 people (Klinenberg, 2002, 9). Although the Chicago heat wave was tragic, it pales in comparison to the European heat wave that killed over 70,000 people across Western Europe in the summer of 2003 (Stone, 2012, 12).

Extreme heat events disproportionately impact vulnerable populations. These vulnerable populations include children, socially isolated persons, and, in particular, elderly persons (Klinenberg, 2002, 80). The EPA reports that individuals 65+ are "several times more likely to die from heat-related cardiovascular-disease than the general population" (EPA, 2016b). When elderly persons are also poverty-stricken and socially isolated, they are at particularly high-risk from heat-related deaths (Semenza, et al, 1996). Semenza, et al (1996) found that living alone doubled the risk of death during the 1995 Chicago heat wave. The high death toll from recent heat waves helped local governments recognize the need for having extreme heat event response plans, including identified cooling centers and public education, before heat waves strike (Bernard and McGeehin, 2004; Stone, 2012, p. 6; Lowe, Ebi, & Forsberg, 2011, pp. 4624–4625).

2.1.1.2 Heat response plans. Like many other disasters, the attitude toward heat waves has largely been one of resignation—the disaster will come, and there is little we can do prevent it (in on other words, the disaster is an "act of god") (Steinberg, 2006, pp. 24, 47, & 68). It is probably for this reason that much of the planning-related research on heat waves has focused on response plans, rather than plans aimed at reducing risk in advance of heat waves. Response plans guide government efforts to reduce heat-related illness and death in the days immediately preceding a heat wave as well as during the event itself (Bernard and McGeehin, 2004; Lowe, Ebi, & Forsberg, 2011). These plans usually focus on getting the word out when an EHE is about to strike and developing cooling centers for vulnerable populations without access to air conditioning. One reaction to the 2003 European Heat wave—an event that is estimated to have killed around 70,000 people—was the development of heat response plans by governments aware of their jurisdiction's vulnerability to heat waves (Stone, 2012, p. 6; Lowe, Ebi, & Forsberg, 2011, pp. 4624 & 4625).

There has been limited analysis of heat plans in general, despite the obvious threat of heat waves in developed areas. The little research that has been done has focused on heat response plans. Bernard and McGeehin (2004) looked for heat response plans from 18 cities deemed at-risk for heat waves. After reviewing the ten plans they located, about half of which the authors called "cursory" in the treatment of heat waves, Bernard and McGeehin formulated a list of six qualities of good heat response plans:

- Identification of a lead agency and participating organizations;
- Use of a consistent, standardized warning system activated and deactivated according to weather conditions;
- Use of communication and public education;
- Implementation of response activities targeting high-risk populations;
- Collection and evaluation of information; and
- Revision of the plan (p. 1520).

These response plans appear to have limited success, however. Sheridan (2007) found that individuals in four different North American cities were uncertain what to do during an extreme heat event (p. 3). Bernard and McGeehin also reported that five of the response plans they analyzed included fan distribution programs "despite evidence that fans do not reduce mortality risk during heat waves and can increase heat stress if used improperly" (p. 1520). Clearly, simply responding to heat waves is not an effective strategy. To truly have a lifesaving impact during heat waves, local governments must focus on mitigating the land use decisions that are already causing heat waves to increase in frequency and severity.

2.1.2 Heat waves, climate change, and urban heat islands. In the following section, I explain the concepts of local climate change and urban heat islands. I then outline heat wave mitigation, including the three most effective mitigation strategies that local climate change experts have identified.

2.1.2.1 Local climate change and urban heat islands. The reason that heat wave response plans fall short can be summed up in one concept: local climate change. Local climate change refers to the urban heat island—the phenomenon that cities are warming at a faster rate than the global average. Climate change, however, is typically talked about at a global level (Stone, 2012, pp. 13–14)—global sea level rise, global temperature change, global CO2 levels. This emphasis on global climate change creates a problem because the global scale skews what happens at the local scale. As Stone points out,

> Were these [local] temperature measurements not modified [to global averages], we would find that the environments in which we live are actually warming at a substantially higher rate than the planet as a whole, with troubling implications for anyone who lives, works, or owns property in cities (p. 14).

The global scale creates a second problem: it makes climate change seem distant both geographically and temporally. However, climate change is at the doorstep of many urban areas that have not even recognized it as a legitimate concern. One of the ways that local climate change will manifest itself is in increased heat wave intensity and frequency. Habeeb, Vargo, and Stone (2014) found that four heat wave characteristics—frequency, duration, intensity, and timing—each increased significantly between 1961 and 2010 in 50 large US cities. These findings should serve as a wakeup call for US cities in their preparation for climate change. Although Habeeb, Vargo, and Stone's findings are significant, they miss an important segment of the country: Nine interior states were not represented in their study; of these nine states, all but three were located in the Great

Plains climatic region. This reflects the overall focus towards larger, coastal cities in heat wave research specifically and climate change research generally.

2.1.2.2 Heat wave mitigation. Another focus in climate change literature and mitigation/adaptation strategies is towards greenhouse gas (GHG) emission reduction (Stone, 2012, p. 89). But GHG reduction is not the only, or even the most effective, strategy for addressing local climate change. Stone argued that "land-surface changes are the single most effective option available to cities to counteract the very real threats of climate change during the next half-century" (p. 99). He went on to say that, "many do not consider changing the weather in cities to be a viable policy option for managing environmental problems. Yet, it should be" (p. 103).

Two leading cities with plans for addressing heat wave mitigation are Melbourne, Australia, and Louisville, Kentucky (B. Stone, personal communication, December 12, 2016). The City of Melbourne Climate Adaptation Strategy contains a section dedicated to extreme heat and brushfire adaptation. Although the plan recognizes that "the highest value adaptation measures are those that can manage the microclimate of the City of Melbourne to be less sensitive to temperature rises and provide improved thermal performance of the urban environment" (City of Melbourne, 2009, 69), the extreme heat implementation section does not include any efforts focused on managing the microclimate. Because of the lack of land use implementation measures and because the plan was for an international city when this research covers only domestic areas, I decided not to use the Melbourne plan.

The Louisville, Kentucky, plan—Louisville Urban Heat Management Study—is the "first comprehensive heat management assessment undertaken by a major US city" (Urban

Climate Lab, 2016, 2). It takes a neighborhood-by-neighborhood approach to heat wave mitigation. The plan identifies three categories of land-based heat mitigation strategies—(1) albedo-enhancement ("cool materials"), (2) vegetation-enhancement ("greening"), and (3) energy efficiency—and recommends a combination of strategies best suited for each neighborhood. These three categories are based on research done at the Georgia Institute of Technology's Urban Climate Lab (Stone, 2012; Stone, Vargo, Liu, Hu, & Russell, 2013) and are the categories I looked for in the county hazard mitigation plans I collected. I chose to use the Louisville Urban Heat Management Study because it is the most up-to-date, accurate, and land use-action-oriented heat wave plan in the United States. It was also developed for a city located in an interior state, showing that municipalities located in interior states can develop comprehensive heat mitigation strategies.

2.1.2.2.a Cool materials strategies. Cool materials enhance a surface's albedo. Albedo is a surface's capacity to reflect the sun's energy; sometimes thought of as the surface's "whiteness" (Urban Climate Lab, 2016, p. 14). Cool materials strategies help decrease a city's vulnerability to heat by increasing the amount of solar radiation reflected back into space, thus reducing the amount of energy absorbed by buildings and impervious surfaces. Reduced heat absorption means that buildings take less energy (and money) to cool and decrease reliance on the energy grid during extreme heat events. Common albedo-enhancement strategies include cool roofing and paving materials (usually light-colored shingles and asphalt).

2.1.2.2.b Greening strategies. Greening strategies utilize the natural cooling effects of plants to help cities mitigate heat (Urban Climate Lab, 2016, p. 15-17; Stone, 2012, pp. 97-126). Vegetation is an effective cooling strategy for two reasons. First, evapotranspiration—a plant-based process that uses the sun's energy to turn water into water vapor—allows plants to absorb solar energy. Second, plants, especially trees and bushy vegetation, shade buildings and the ground, thus preventing these impervious surfaces from absorbing the sun's energy (and later releasing it at night, a problem that keeps cities from cooling off). Common vegetation-enhancement strategies include planting trees, converting barren land and impervious surfaces such as parking lots to grass or native vegetation, and creating greenroofs on flat-roofed buildings.

2.1.2.2.c Energy efficiency strategies. Every time an activity is done that requires energy, from complex industrial processes to the everyday activities of humans, some of the energy is lost; the lost energy is called waste heat (Stone, 2012, p. 76). Waste heat can make up a significant portion of a city's urban heat island. Energy efficiency heat mitigation strategies focus on reducing the amount of waste heat produced in a city. Common strategies include reducing the number of vehicle miles driven and increasing the energy efficiency of buildings through better insulation and weatherization practices (Urban Climate Lab, p. 17-18).

2.1.2.2 Mitigation scale. Researchers have found that the smaller the geographic scale, the better the heat wave mitigation strategies. The local scale is, therefore, the best for understanding the most effective implementation (see Urban Climate Lab, 2016). Harlan, Brazel, Prashad, Stefanov, and Larsen (2006) found wide variation in temperature between eight Phoenix neighborhoods. The variation was greatest between poor, inner-city neighborhoods with little vegetation and limited access to other cooling strategies (such as air conditioning or swimming pools) and more affluent suburbs (p. 2860). Gober et al (2009) wanted to find "how to achieve the greatest nighttime cooling while using the least water possible" in Phoenix neighborhoods (p. 110). They studied the effectiveness of using three mitigation strategies—irrigated vegetation, infill development (meaning development covering formerly vacant lots or replacing parking lots), and water conservation efforts—to mitigate the effects of urban heat islands in ten Phoenix census tracts. Gober and colleagues found that the effectiveness of the three strategies varied depending on the current land use characteristics of a given tract. Generally, they found that areas with the least irrigated vegetation would benefit the most from adding vegetative surfaces whereas additional vegetation had limited impact on tracts with higher levels of irrigated vegetation already in place.

Heat wave mitigation strategies are most effective when they are targeted at a specific location. The type of mitigation strategy needed can differ across a city and certainly differs between climatic regions. As Harlan, Brazel, Prashad, Stefanov, and Larsen (2006) pointed out,

> Although increasing tree cover and planting green open spaces are obvious responses to the UHI in a temperate city, such as Chicago, in arid climates the benefits of adding vegetation must be weighed against potential water shortages. Policies for UHI mitigation and the attendant health benefits of doing so must be carefully articulated with other urban environmental issues, such as long-term land preservation, water supply, and air quality (p. 2861).

This statement largely forms the foundation for one of my research questions: do hazard mitigation plans reflect regional differences in the types of heat wave mitigation strategies included in plans?

2.2 Plan Evaluation

Cities need to plan for and mitigate heat waves, but are cities planning properly? Plan evaluation literature provides a method for evaluating hazard mitigation plans to determine the comprehensiveness of the heat sections as well as variables that influence the types of strategies included in the plans. In the following section, I outline the plan evaluation literature with special consideration of plan quality and hazard mitigation plan evaluation studies.

2.2.1 Plan evaluation research introduction. Plan evaluation is an established research concept in urban planning (Berke and Godschalk, 2009). The purpose and success of urban planning have always been topics of debate (Klosterman, 1985, p. 1). Even advocates of planning recognize that there is often a "tremendous gap between planning's potential and its performance" (p. 13). One way urban planning researchers try to measure the gap between planning's potential and performance is by analyzing plans. Urban plans in their various forms—comprehensive plans, hazard mitigation plans, climate adaptation plans, sustainability plans, etc.—form the foundation of the field of urban planning. Most urban planners are involved in either plan creation or implementation (or both). Because plans and planning documents are central to the planning profession, the documents can help practitioners and researchers understand whether or not planning is fulfilling its potential. Plan evaluation research has largely focused on plan quality of comprehensive plans and other types of community plans, particularly hazard mitigation plans (HMPs).

2.2.1.1 Plan quality. Plans can be useful tools in helping a community achieve their vision and goals. But plans are more likely to fulfill these purposes when they are high-quality: "[h]igh-quality plans draw attention to issues that are often ignored, enhance communication and understanding, and provide clear guidance to implementation decisions" (Berke et al, 2006, p. 585). Notable plan evaluation methods have been developed for comprehensive plans to determine the quality of sustainability efforts (see Berke & Conroy, 2000) and hazard mitigation plans (see Lyles, Berke, & Smith, 2014a; Lyles, Berke, & Smith, 2014b; Berke, Smith, & Lyles, 2012).

Finding high quality plans can be a challenging task. Berke and Conroy (2000) found that comprehensive plans often only provided a cursory framework for sustainability, even when the community identified sustainability as a key concept for formulating the plan. Similarly, Lyles, Berke, and Smith (2014a) found that hazard mitigation plan quality tends to be low to moderate. Berke and colleagues (2006) identified four characteristics of high-quality plans:

> (1) a clear identification of issues important to the community;
> (2) a strong fact base that incorporates and explains the use of evidence in issue identification and the development of policies;
> (3) an internal consistency among issues, goals, objectives, and policies; and
> (4) the monitoring of provisions to track how well objectives and goals are achieved (p. 585).

Berke and colleagues used these characteristics to measure aspects of implementation, and the authors found that high quality plans had a significant impact on permit conformance to land use plans (p. 594). This suggests that, among other things, high quality plans can help cities achieve the community's vision as identified in the plan.

Similar characteristics have been used to test other questions related to plan evaluation. In their research on hazard mitigation plan quality in six US states, Lyles, Berke, and Smith (2014) further divided the four characteristics into seven principles of plan quality (p. 90), broadly grouped as direction-setting principles (goals, fact base, and policies) and action-oriented principles (participation, inter-organizational coordination, implementation and monitoring). They found that there is wide variation in hazard mitigation plan quality principles (p. 93). On a ten-point scale, the principle that ranked highest was implementation with an average of 5.9 points; the inter-organizational coordination principle scored lowest with an average of 1.8 points. Not only does this suggest low overall hazard mitigation plan quality, it also indicates a lack of important connections between emergency managers and land use managers.

Although there are numerous plan evaluation studies, most of them focus on the quality of the entire plan rather than a specific indicator (see Berke and Godschalk, 2009; for exceptions, see Berke et al, 2006). While understanding the quality of a plan as a whole is important, this approach generalizes either good or bad qualities across all sections of the plan. There may be instances where a city is doing particularly well in one area (for example, flooding in a hazard mitigation plan) but is completely missing a different, yet similarly critical, concept (such as heat waves). Only by focusing on more specific sections will researchers be able to determine if there is variation in quality within the plan itself. My thesis helps to bridge this gap by focusing solely on heat waves and heat wave mitigation strategies.

2.2.2 Hazard mitigation plan evaluation. In the following sections, I define the term mitigation as used in emergency management compared to other disciplines as well as how it is used in this research. I then provide the national historical and legal context for hazard mitigation planning. Finally, I examine the hazard mitigation plan evaluation literature.

2.2.2.1 Defining mitigation. The term "mitigation" is essential to, but used differently by, emergency managers and environmental scientists. In environmental science, the term "climate mitigation" refers specifically to policies and efforts that limit greenhouse gas emissions, such as reducing the number of vehicle miles travelled (United Nations Environment, n.d.). In emergency management, however, "hazard mitigation" refers to any actions taken to reduce vulnerability to disasters (Godschalk, 2003, p. 136). Hazard mitigation efforts can include building sea walls to reduce the impact of hurricanes on coastal development, educating individuals about the risk of hurricanes, and/or limiting development on beachfront property.

Within this thesis, there is a further distinction between hazard mitigation efforts aimed at preventing or reducing the severity of a hazard *before* it occurs and efforts aimed at reducing death and injury *during* the hazard. I refer to the actions taken before the hazard as "land use mitigation strategies" or simply "mitigation strategies;" these include the three main categories of mitigation strategies—cool materials, greening, and energy efficiency strategies. I refer to the actions taken during the hazard as "response strategies;" these include efforts to set up cooling centers, educate individuals about heat waves, distribute fans, or fix A/Cs.

Other researchers have made similar distinctions between types of mitigation. For example, Lyles, Berke, and Smith (2014a, p. 93) referred to these policies, respectively, as "preventative land use policies" and "emergency services policies." Lyles, Berke, and Smith (2014b) explained, "Land use approaches can direct people and property into more (or less) hazardous areas and thereby reduce hazard risks by controlling the timing, location, type, intensity and other characteristics of development" (p. 792). In the case of heat waves, the hazard can strike any area within a jurisdiction so land use strategies cannot move people out of harm's way; instead, land use strategies can actually influence the intensity of the heat wave.

2.2.2.2 Hazard mitigation, hazard mitigation planning, and the Disaster Mitigation Act. Hazard mitigation is generally defined as any efforts taken to reduce the impact of disasters on human life and property (FEMA, 2017). The most effective hazard mitigation is comprehensive, long-term in its timeframe, and focused on permanent adjustments to human actions rather than government response when disasters strike (FEMA, 2017; Lyles, Berke, and Smith, 2014a and 2014b). Hazard mitigation planning allows communities to consider the types of hazards they could face and to outline the actions they can take to reduce the impacts from those disasters. Although creating a hazard mitigation plan can be time-consuming and costly, there are advantages to having a plan. The Federal Emergency Management Agency (FEMA) outlined six purposes of hazard mitigation planning (FEMA, 2016):

- Increase education and awareness around threats, hazards, and vulnerabilities;
- Build partnerships for risk reduction involving government, organizations, businesses, and the public;
- Identify long-term, broadly-supported strategies for risk reduction;
- Align risk reduction with other state, tribal, or community objectives;
- Identify implementation approaches that focus resources on the greatest risks and vulnerabilities; and
- Communicate priorities to potential sources of funding.

Despite these benefits, hazard mitigation planning was done on a limited scale before it was federally mandated (Lyles, Berke, & Smith, 2014b, 793).

On a local level, the benefits of hazard mitigation can be skewed by the perception of expense or inconvenience because natural hazards are relatively unlikely to strike a given municipality (Lyles, Berke, & Smith, 2014a, p. 89). On a state or federal level, however, the benefits of requiring individual municipalities to prepare for hazards far outweighs the costs. Planning for and mitigating the effects of disasters can result in millions or billions of dollars in state and federal government savings when a disaster does strike. The US Congress determined that mandating hazard mitigation planning at the local government level is in the best interest of the American people. In 2000, Congress passed an amendment to the Robert T. Stafford Disaster Relief and Emergency Assistance Act (FEMA, 2013). The amendment, referred to as the Disaster Mitigation Act (DMA), updated requirements for state, local, and tribal pre-disaster mitigation planning. Most significantly, the DMA introduced a mandate requiring local hazard mitigation plans (HMPs). The purpose of the DMA was to make hazard mitigation in the US a more proactive, rather than reactive, process (Lyles, Berke, & Smith, 2014a, p. 90). By some measurements, the DMA's purpose was achieved. In 2012, all 50 states and 26,000 jurisdictions had an HMP (Department of Homeland Security Office of the Inspector General, 2012). However, further research on HMP quality and hazard mitigation strategies suggests that the US still has a long way to go before hazard mitigation is truly proactive (Lyles, Berke, & Smith, 2014a and 2014b).

2.2.2.3 Hazard mitigation planning research. Research on hazard mitigation plans has largely focused on two areas: plan quality and inclusion of land use mitigation strategies.

2.2.2.3.a Hazard mitigation plan quality. Since passage of the DMA, researchers have studied multiple aspects of hazard mitigation plans to determine whether the plans achieve their intended purpose of making communities more resilient to disasters. Overall, researchers have found that HMPs in the United States are of "mediocre quality" (Lyles, Berke, and Smith, 2014b, p. 792). As mentioned earlier, one issue that contributes to the mediocre quality of HMPs is that local governments have less incentive to plan for disasters than federal and state governments have to require hazard mitigation planning (Lyles, Berke, and Smith, 2014a, p. 89). In other words, local governments may participate in hazard mitigation planning largely to fulfill a mandate rather than to commit to mitigating future hazards; this "checking-the-box" mentality seems to result in lower-quality plans. The low-to-moderate plan quality holds across the six states included in Lyles, Berke, and Smith's study. "No state is the clear leader in local mitigation plan quality… [and] no state is the clear laggard either" (p. 94).

2.2.2.3.b Inclusion of land use strategies. Under the DMA, the primary local agents in charge of writing the mitigation plan changed from city planners to emergency managers (2014b, p. 793). This change in plan writers may have also resulted in a shift in the types of mitigation strategies included in the plans. Lyles, Berke, & Smith (2014b) found that when local planners were included in the hazard mitigation plan development process, the number of land use mitigation strategies increased significantly (p. 807). This suggests that planners who have a strong understanding of local land use policies can influence the strength and type of strategies included in the plans. Lyles, Berke, & Smith (2014b) also found that state planning policy context had a strong positive relationship on the inclusion of land use mitigation strategies (p. 802).

2.3 The need for heat wave mitigation evaluation

The literature reviewed above demonstrates four main points. First, heat waves are climate-related disasters that can kill thousands of people in a single event. Second, climate change is happening at the local scale as well as the global scale. Third, land use strategies can help mitigate climate-related hazards at the local scale. There are three different categories of land use strategies that can specifically be used to mitigate heat waves. Fourth, plan evaluation is an established research method used to understand how communities are preparing for hazards.

Hazard mitigation plans are the tools communities use to prepare for future disasters. Climate-related disasters such as heat waves are increasing in intensity and frequency due to climate change. But researchers have yet to determine how well communities, especially in interior states where the threats of climate change are not as evident as sea level rise on the coast, are preparing for climate-related hazards. Ultimately, the knowledgebase developed by social and climate scientists about climate-related hazards will do little if communities and individuals are not utilizing the information to better prepare for the future.

The plan evaluation and heat wave research to date has identified variables important to understanding whether local governments are preparing for heat waves, but the questions of how they are preparing for specific hazards and whether the preparation is high quality have not been answered. Using county hazard mitigation plans and looking specifically at counties in the interior US, I attempt to answer these questions.

Although hazard mitigation plan studies to-date offer insight into the overall quality of plans and the types of strategies included, the research is largely limited to coastal areas

(Lyles, Berke, & Smith, 2014a and 2014b). The studies have focused on the entire plan rather than analyzing strategies related to specific hazards. This approach generalizes the quality of the plan across each hazard despite the potential for variations in fact-base and implementation strategies between hazards. Of particular importance, research has not looked at the types of heat wave mitigation strategies included in HMPs from the interior US.

My research differs from other plan evaluations in three ways. First, I focus on cities and counties in non-coastal states. Second, I analyze the fact-base and mitigation strategies for a specific type of hazard—heat waves. Third, I consider the actions used to mitigate other hazards that could have co-benefits for mitigating heat waves.

Chapter 3: Methods

In this chapter I explain the methodology I used to answer my research questions. First, I describe my research design and the unit of analysis I chose. I then explain my sampling approach. Next, I explain my data collection process. Finally, I outline the data analysis processes I used.

3.1 Research Design

I used a cross-sectional, multi-state approach to analyze county hazard mitigation plans from six US states. This approach helped me answer my three research questions: 1) does a county's climatic region impact the strategies it uses to mitigate heat events? 2) does a county's climatic region impact the strategies included in its hazard mitigation plan that could have heat wave mitigation co-benefits? and 3) what variables influence the comprehensiveness of a plan's heat section? A research design consideration was which type of plan to use as the unit of analysis. Another research design consideration was which regions, states, and counties to focus on.

3.1.1 Unit of analysis. I chose county hazard mitigation plans (HMP) as the unit of analysis for four main reasons. First, the Disaster Mitigation Act of 2000 requires a Federal Emergency Management Agency (FEMA)-approved local hazard mitigation plan for local governments to receive certain types of federal disaster assistance (FEMA, 2013). I determined that most counties would have a formally adopted hazards mitigation plan because federal funding is attached to the plan's successful completion. Second, the Disaster Mitigation Act of 2000 requires jurisdictions to update their HMPs every five years. HMPs are intended as living documents, reflecting the current hazards a community faces and the best practices for mitigating those hazards. Third, other researchers have studied HMP quality and mitigation strategies (see Lyles, Berke, & Smith, 2014a; Lyles, Berke, & Smith, 2014b; Berke, Smith, & Lyles, 2012). Fourth and finally, the recent trend in hazard mitigation planning is creating plans for a geographic area larger than a city, in part because disasters do not follow jurisdictional boundaries and because larger areas typically have more resources to plan for and respond to disasters.[1]

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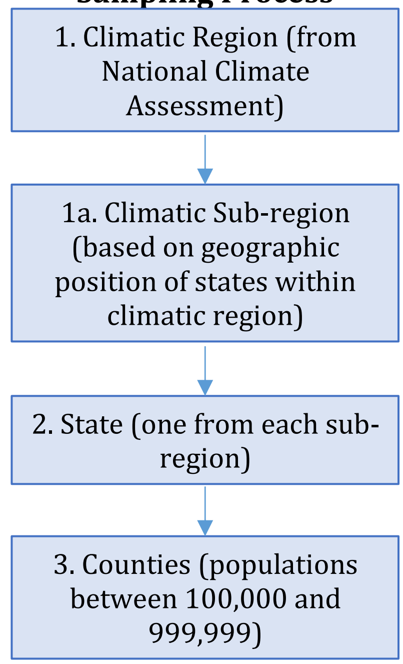
[1] Because cities usually suffer more from heat due to the urban heat island (UHI) effect, I originally attempted to collect city-specific hazard mitigation plans. However, cities did not have their own HMP. Instead, a county and the municipalities located within that county collaborated on a county-wide hazard mitigation plan. As such, I collected the plan from the county level with the understanding that these plans reflect the needs of the most and least populated jurisdictions within the county.

3.2 Sampling

To generate a representative sample for an understudied portion of the US, I used the following three-stage sampling process (see Figure 3.1). 1) I determined the climatic regions and the climatic sub-regions. 2) I randomly selected the states from the sub-regions. 3) I selected the counties based on population.[2]

Figure 3.1
Sampling Process



3.2.1 Regions. Most of the research on heat wave planning has focused on large cities such as Phoenix, Chicago, and Atlanta (see Klinenberg, 2002; Stone, 2012; Gober et al, 2009; Harlan, Brazel, Prashad, & Stefanov, 2006; Stone, 2007; Stone, Vargo, & Habeeb, 2012; Habeeb, Vargo, & Stone, 2015). Similarly, research on climate adaptation and hazard mitigation planning has focused on cities in coastal states (see Lyles, Berke, & Smith, 2014a; Lyles, Berke, & Smith, 2014b; Berke, Smith, & Lyles, 2012). One of the purposes of this research is to help fill in gaps about heat wave mitigation and climate adaptation in interior states and in areas with populations less than 1,000,000.

Increased heat intensity is cited by the 2014 National Climate Assessment as one of the hazards likely to increase in all regions of the US. The National Climate Assessment breaks the contiguous United States into six regions. Three of these regions are considered in this paper: the Great Plains, the Southwest, and the Midwest. Figure 3.2 shows the states included in each region. These regions were chosen because they are adjacent to each other, represent most of the interior US (20 of the 27 states that do not border an ocean are

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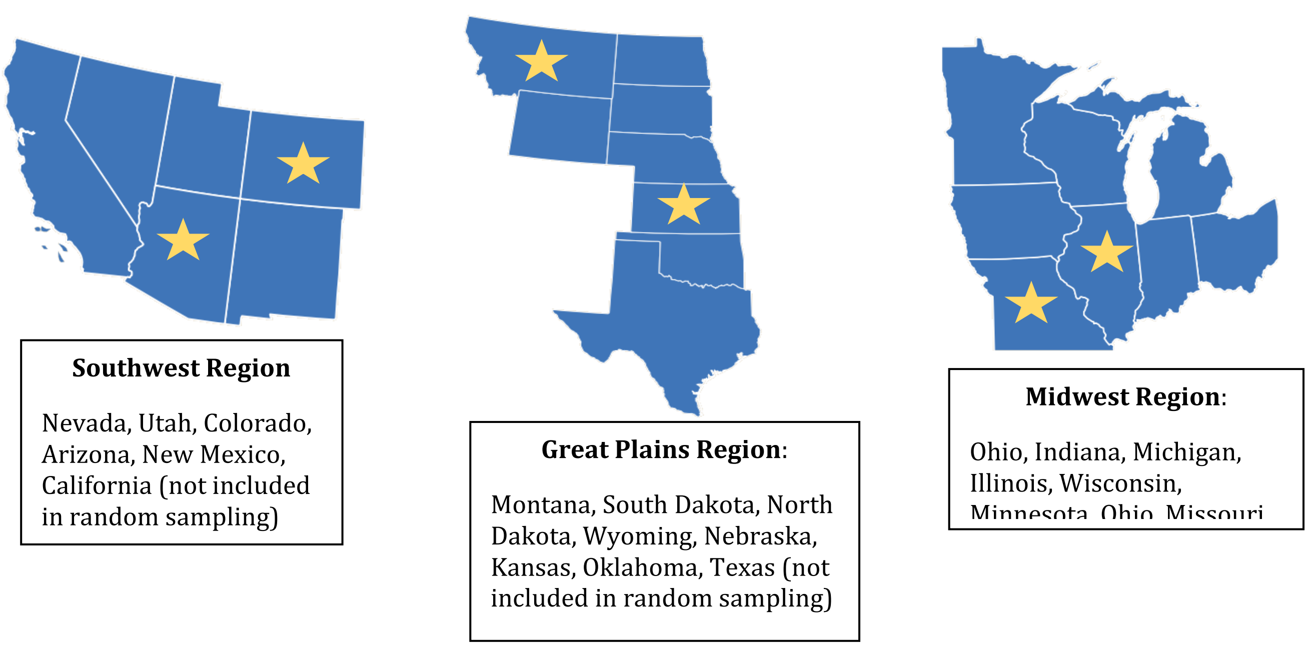
[2] In a larger project, it would be beneficial to sample county plans from all the states in the three climatic regions. Such an extensive collection was not possible given the time constraints for my thesis but should be pursued at a later time.

represented in the regions), and offer a geographically diverse sampling of climates (from deserts and high mountains to prairies and the Great Lakes).

The regions identified by the National Climate Assessments (NCA) are geographically broad resulting in wide variations within the same region. For example, Montana and Oklahoma are both included in the Great Plains despite having very different climates. In order to overcome this problem, I divided the NCA regions in half so that the states I sampled would represent as much of the interregional climatic diversity as possible. The interregional groupings are:

- Great Plains: northern vs. southern half of region (more snow in north)
    - Northern GP: South Dakota, Montana, North Dakota
    - Southern GP: Kansas, Wyoming, Nebraska, Kansas
- Southwest: northern vs. southern half of region (more snow in north)
    - Northern SW: Utah, Colorado, Nevada
    - Southern SW: Arizona, New Mexico
- Midwest: eastern vs. western (precipitation greatest in the east)
    - Eastern MW: Indiana, Ohio, Michigan, Illinois, Wisconsin
    - Western MW: Missouri, Minnesota, Iowa

Figure 3.2: Climatic Regions and Selected States



3.2.2 States. I selected two states from each region for inclusion in this research using a two-step process. In step one, I excluded California and Texas from the analysis, a choice made for two reasons. First, they are the only states in the three regions with ocean coastlines. Second, six of the ten largest cities in the United States are located in these two states. One of the purposes of this research is to build an understanding of how urban areas with populations less than 1,000,000 are dealing with the potential impacts of climate change. As such, I determined that the huge cities in California and Texas could skew the results.

In step two, I used a random number generator to choose which states to retrieve county hazard mitigation plans from. The following states were chosen from each sub-region:

- Great Plains North: Montana[3]
- Great Plains South: Kansas
- Midwest East: Indiana
- Midwest West: Missouri
- Southwest North: Colorado
- Southwest South: Arizona

3.2.3 Counties. After the states were randomly selected, I downloaded county level population data from the U.S. Census Bureau's American FactFinder for the 2010 Census. I only analyzed plans from counties with populations over 100,000 in an attempt to capture areas that are potentially impacted by UHI. I also collected each county's population density so that I could measure whether population, density, or both influence the types of

[3] South Dakota was originally selected using the random number generator. However, South Dakota only has two counties that meet the population threshold of 100,000, and only one county has a hazard mitigation plan. The random number generator was used to choose between looking at plans in either Montana or North Dakota; Montana was selected. Although Montana also only has two counties that meet the population threshold, both counties have an HMP. Changing to Montana doubled the amount of representation from the Great Plains North sub-region.

strategies included in the plans or the comprehensiveness of the heat hazard section. Altogether, 54 counties met the population criteria of between 100,000 and 999,999 people. I located plans on county or city emergency management websites for all counties except McLean County, IL, which did not have a hazard mitigation plan as of December 2016.

3.2.3.1 Multi-county plans. While searching for HMPs, I discovered that some of the plans covered more than one county. In all, seven plans (14.9%) are multi-county plans. Three plans (Weld, CO; LaSalle, IL; Jasper, MO) cover multiple counties but only one county has a population over 100,000. Four plans cover more than one of the 53 counties under consideration. I decided to only use the county with the largest population in the. I chose to use the county with the largest population because the area with the largest population likely has the most political clout and, therefore, the largest influence on the plan's development. These plans are:

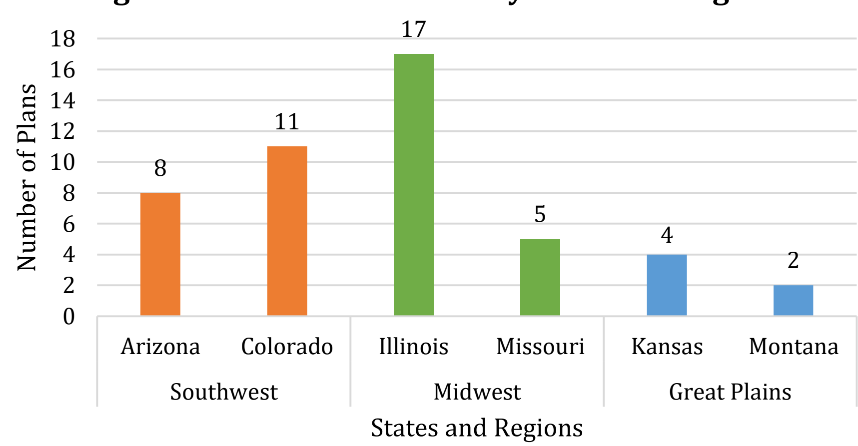
- Regional Multi-Hazard Mitigation Plan for Cass, Clay, Jackson, Platte and Ray counties in Missouri: Jackson County covers most of Kansas City, MO. It is the largest of the counties, so it is the county included in this analysis. Only Clay and Jackson Counties met the population requirements for this study.
- Region L Multi-Jurisdictional Hazard Mitigation Plan for Leavenworth, Wyandotte, and Johnson counties in Kansas: Johnson County is the most populated of the three counties, so it is the county included in this analysis. Leavenworth County did not meet the population requirements for this study.
- St. Louis Regional Hazard Mitigation Plan for Franklin, Jefferson, St. Charles, St. Louis Counties and the City of St. Louis in Missouri: This area is known as the "St. Louis" region, suggesting the county's and city's influence in the area. St. Louis County is also

the most populated of the four counties, so it is the county included in this analysis. All of the counties met the population requirements for this study.

- Tri-County Regional Planning Commission Natural Hazard Mitigation Plan for Peoria, Woodford, and Tazewell counties in Illinois: Peoria is the most populated of the three counties, so it is the county included in this analysis. Only Peoria and Tazewell met the population requirements for the study.

In total, I located 47 plans from state and county websites and downloaded them as .pdf documents. Figure 3.3 summarizes the number of plans from each state and region. The largest number of plans, seventeen (34%), came from Illinois. The fewest plans, two (4.3%), came from Montana. Nearly half (22 plans; 46.8%) of the plans represent the Midwest region. Another nineteen plans (40.4%) represent the Southwest region. 12.8% of the plans represent the Great Plains region.

Figure 3.3 Number of Plans by State and Region



3.2.3.2 County population and population density. An equal number of counties (12; 25.5%) fall into the large and medium population categories. Nearly half (23; 48,9%)

of the counties are categorized as small. The average population and population density of the population categories are outlined in Figure 3.4.

Figure 3.4: County Population Data		
County Population Category	**Population**	**Population Density per Square Mile**
Small (100,000 to 249,999) N: 23	Avg.: 147,942 Range: 105,160—211,033 S.D.: 36,657	Avg.: 163.7 Range: 7.2—580.70 S.D.: 201.4
Medium (250,000 to 499,999) N: 12	Avg.: 322,230 Range: 252,852—498,365 S.D.: 76,416	Avg.: 346.1 Range: 63.4—575.2 S.D.: 172.3
Large (Over 500,000) N: 12	Avg.: 694,978 Range: 515,269—998,954 S.D.: 174,261	Avg.: 1346.3 Range: 106.7—3922.6 S.D.: 1093.8
All N: 47	Avg.: 332,110 Range: 105,160—998,954 S.D.: 246,241	Avg.: 512.2 Range: 7.2—3922.6 S.D.: 743.8

3.2.3.3 Political identity. 24 (51.2%) of the counties voted Democrat in the 2012 Presidential Election. 23 (48.9%) of the counties voted Republican.

3.3 Data Collection

I collected three categories of data: county characteristics, plan characteristics, and heat wave data. For the variables included in plan characteristics and heat wave data, I used a coding approach similar to coding done by other plan evaluation studies (see Lyles, Berke, and Smith, 2014a, p. 92). I used a binary and ordinal coding system for each nominal and ordinal variable. In the case of binary items, a 0 was coded if the item was not included in the plan; a 1 was used if the item was included. In the case of ordinal items, a 0 was used if the item was not included in the plan; the numbers 1 through 8 were used to identify the variations of the item in question (see Appendix Table 1 for more details). Other plan evaluation research has typically relied on more than one coder to ensure coding consistency (see Lyles, Berke, and Smith, 2014a, p. 92; Berke & Godschalk, 2009). One of the limitations of my research was that I was the only coder. As such, I was unable to strictly ensure coding consistency or to reconcile coding differences. If this research is undertaken again, having multiple coders would strengthen the results. To help overcome the limitation of having only one coder, I read through each plan three times and updated my data if I found inconsistencies.

The first data I collected on the plans was whether they contained a heat section (a segment entirely or mostly dedicated to defining and identifying the threat from heat hazards). I then collected information on what the planners included in the heat section and developed a 10-point evaluation system so that I could compare sections across plans (see section 3.3.1). Finally, I searched the implementation sections in each plan for the three categories of heat wave mitigation strategies (cool materials, greening, and energy efficiency strategies) identified by the heat wave literature (Stone, 2012; Stone, Vargo, Liu, Hu, & Russell, 2013; Urban Climate Lab, 2016). I had to adjust the way I looked for the strategies because only a few plans identified strategies specifically related to heat wave mitigation. I outline this adjustment in section 3.3.2.

3.3.1 Heat section rankings. To consistently evaluate the heat sections included in the plans, I developed a 10-point ranking system to help me systematically rate sections. Lyles, Berke, and Smith (2014a) developed a similar 10-point system for their comparison of the hazard mitigation plan quality in six US states. Figure 3.5 outlines the variables I included in the ranking system and the number of points given to plans based on the variables. I chose these variables to reflect aspects of both the fact base and the planning context that other researchers have identified as important to the quality of plans (Berke, Smith, and Lyles, 2012; Lyles, Berke, and Smith, 2014a and 2014b).

Berke, Smith, and Lyles (2012) explained that the fact base principle “provides the empirical foundation to ensure that key hazard problems are identified and prioritized, and mitigation policy-making is well-informed (p. 140). Four of the variables included in the heat section ranking system (see Figure 3.5) help establish the robustness of the heat hazard fact base included in a plan. Because extreme heat events are exacerbated by the urban heat island effect (Habeeb, Vargo, and Stone, 2014), I use whether urban heat island is explained in the heat section, anywhere in the plan, or not explained to test for foundational understanding about what influences heat hazards. I use heat section length to test for the fact base as longer sections tend to contain more information. The heat hazard severity and probability ratings test whether communities understand and prioritize the threat of heat hazards.

Part of the overall planning context includes experience with natural hazards (Lyles, Berke, and Smith, 2014b, p. 797). I used the inclusion of information about historical heat waves to test for experience with heat hazards. Zahran, Brody, Vedlitz, Grover, and Miller (2008) found that the number of people killed by extreme weather events influenced a city’s willingness to voluntarily commit to the Cities for Climate Protection campaign (p. 544). To ensure that my data captured the importance of experiences with heat-related deaths, I included whether a plan included the number of deaths caused by heat waves in the historical heat waves variable.

Figure 3.5: Heat Section Ranking System
1. Heat hazard severity rating included: Yes = 1 point No = 0 points
2. Heat hazard probability rating included: Yes = 1 point No = 0 points
3. Historical heat waves included:

Good, death count provided = 2 points Poor, no death count provided = 1 point None = 0 points
4. Urban heat island referenced: Yes, in heat section = 2 points Yes, elsewhere in plan = 1 point No = 0 points
5. Length of heat wave section: 6+ pages: 2 points 1 to 5 pages: 1 point 0 pages: 0 points

The five criteria ranking system had a total of 10 points possible. A score of 0 to 2 received a ranking category of "minimal." A score of 3 or 4 received a ranking category of "limited" (no plans received a score of 3 or 4). A score of 5 to 6 received a ranking category of "moderate". Plans with scores of 7 to 8 and 9 to 10 received ranking categories of "thorough" and "extensive," respectively.

3.3.2 Identifying heat wave mitigation strategies. In this section, I identify the types of heat wave mitigation strategies I looked for in each plan and the method I used to find them. I used heat wave mitigation research that had classified the most effective types of heat wave mitigation (Stone, 2012; Stone, Vargo, Liu, Hu, & Russell, 2013; Urban Climate Lab, 2016) to identify the mitigation strategies to look for in the hazard mitigation plans I collected.

There are three categories of mitigation techniques outlined in the research:

- Cool materials (light-colored roofing and paving materials, pervious pavers, etc.),
- Vegetation (green roofs, parkland, etc.), and
- Energy efficiency (weatherization of buildings, etc.).

In order to identify the strategies included in the 47 plans I collected, I analyzed the implementation section of each plan for land use mitigation strategies that were specifically associated with heat hazards. I determined that searching the implementation section of each plan was the most logical method for two reasons. First, the section identifies the actions that each community is committed to pursuing. (Any strategies that were identified as "removed" or "not being pursued at this time" were not coded.) Second, actions suggested throughout the plan are harder to find and so may be less frequently referenced by those trying to implement the plan.

As discussed more thoroughly in Chapter 4, I found that only five plans included any land-use mitigation strategies specifically aimed at reducing the threat of heat hazards. I then returned to the implementation sections to look for cool materials, greening, and energy efficiency strategies related to any hazards. I determined that efforts to mitigate other hazards using strategies in these three categories would have co-benefits for mitigating heat waves as well—even if the communities have not realized it. The strategies I looked for and the hazards I coded are outlined in Figure 3.6. At this point, I also made notes on response actions related to heat waves so that I could analyze any correlation between response and land-use strategies.

Figure 3.6: Strategies with Co-benefits

Strategy	Description
All Cool Materials Strategies	Cool material strategies used to mitigate any hazard; potential for making links to heat mitigation - None - Decrease impervious surfaces - Increase surface reflectivity - Other cool material strategies
All Greening Strategies	Greening strategies used to mitigate any hazard; potential for making links to heat mitigation - None - Native Vegetation/Landscape Ordinance - Management (of trees and streams/development; includes maintenance) - Tree/Vegetation Planting or Replacement (includes restoration) - Removal/Trimming

	- Participation in Tree City - Green infrastructure/open space (including stream buffers)
All Energy Efficiency Strategies	Energy efficiency strategies used to mitigate any hazard; potential for making links to heat mitigation - None - Building Weatherization/Retrofit - Other Energy - Building code enforcement - Green Buildings
Hazards Mitigated by Cool Materials, Greening, or Energy Efficiency Strategies	Hazards identified in the plan as being mitigated by materials strategies - None - Flood - Drought - Severe Weather (including tornadoes and winter storms) - Other - Heat - All
Heat Response Strategies	The non-land use mitigation strategies (referred to as "response" strategies) identified as reducing the impact of heat. - None - Cooling Centers - Fan Distribution - A/C Repair - Education: includes warnings; may be for "all hazards" - Networks/vulnerable population identification - Implementation of Other Plans

3.4 Analysis

I used both descriptive statistics and bivariate analyses to explore the data I collected. The dependent variables I collected measure the type and quality of heat-related content included in hazard mitigation plans. The independent variables I collected focus on measures of plan and county characteristics expected to influence the inclusion of heat-related content in hazard mitigation plans. Independent variables include the county's population size and whether or not the hazard mitigation plan is a multi-county plan. The full list of variables I considered and some of the descriptive characteristics for the variables can be found in Appendix Table 1.

3.4.1 Descriptive statistics. I calculated the descriptive statistics on each variable appropriate to the level of data. The descriptive statistics I used included mean, median, mode, range, and standard deviation. Appendix Table 1 summarizes these statistics. I also used frequency tables to better understand the percentages across multiple categories. The results are explained more fully in Chapter 4: Results.

3.4.2 Bivariate analysis. I also performed bivariate analyses. For research question 1—which variables influence the heat section ranking—I used the heat section ranking (see section 3.3.3) as the dependent variable. I used the heat section ranking value (0 – 10) to perform correlations between heat section ranking and six variables (see Figure 3.7). I used ANOVA and means tables to calculate relationships between heat section ranking and seven variables (see Figure 3.7).

Figure 3.7: Variables tested for Relationship with Heat Section Ranking

Variable	Rationale	Type of Test
Plan Characteristics		
Multi-county plan	Multi-county plans may have access to more planning resources (see Lyles, Berke, and Smith, 2014a, 92). This may result in a more comprehensive heat section.	ANOVA and means table
Plan length	Longer plans may have more space to discuss heat hazards (even if they are not choosing to emphasize heat hazards).	Pearson's R
Heat Wave Data		
Heat Hazard Word Count	Plans with more frequent references to heat hazards (extreme heat and heat waves) should do a better job of covering heat hazards in the plan.	Pearson's R
Climate Change word count	Plans that mention climate change may be more aware of the hazards associated with climate change that threaten their locality.	Pearson's R

Drought word count	Plans that mention drought frequently may also do a better job of covering heat waves.	Pearson's R
Planner	Plans that included a local planner in the planning process should have a more comprehensive heat section (Lyles, Berke, and Smith, 2014a).	ANOVA and means table
Consultant	Plans that include a consultant may have more comprehensive heat sections because consultants have already researched the hazard.	ANOVA and means table
Heat response strategies	Plans that include heat response strategies may have more comprehensive heat sections because they are more aware of heat hazards.	ANOVA and means table
County Characteristics		
Region	Plans in regions typically associated with heat waves likely have more comprehensive heat sections than in other regions.	ANOVA and means table
State	Heat section comprehensiveness may vary by state even within the same region.	ANOVA and means table
County population	Lyles, Berke, and Smith (2014b) identified population characteristics as important to the local planning context because size can influence planning capacity (p. 797 – 798). Urban heat island is also a more significant problem in urban areas (Stone, 2012). Both reasons may mean that counties with larger populations or higher population densities may have more comprehensive heat sections.	Pearson's R
Population density		Pearson's R
County voting	Zahran, Brody, Vedlitz, Grover, and Miller (2008) found that counties that voted Democrat were more likely to voluntarily commit to the Cities for Climate Protection campaign (p. 544). County voting may be associated with willingness to recognize and prepare for climate-related hazards.	ANOVA and means table

For research question 2—which variables influence the types of heat wave mitigation strategies included in the plans—, I used a Chi-Square test to find relationships between the variables "All Greening Strategies" and "All Energy Efficiency Strategies" and eleven variables. These variables are described in Figure 3.8.

Figure 3.8: Variables included in All Greening Strategies and All Energy Efficiency Strategies Chi-square Tests		
Variable	**Rationale**	**Notes**
	Plan Characteristics	
Multi-county plan	Multi-county plans may have access to more planning resources (see Lyles, Berke, and Smith, 2014a, 92). This may result in more types of mitigation strategies being included in the plans.	
Plan length	Longer plans may have more space to include all types of mitigation strategies.	Tested as both the original, multi-category data and as two category data. The two categories I used are "more than 262 pages" and "262 pages or fewer"; I chose 262 pages chosen because it is the median value.
	Heat Wave Data	
Climate Change word count	Plans that mention climate change may be more aware of strategies that mitigate any climate-related hazard.	Tested as both the original, multi-category data and as two category data. The two categories I used are climate change mentioned "yes" or "no".
Drought word count	Drought is often associated with extreme heat events. Plans that mention drought frequently may include more strategies that could be used to mitigate both hazards.	Tested as both the original, multi-category data and as two category data. The two categories I used are "more than 92 words" and "92 or fewer words"; I chose 92 chosen because it is the median value.
Planner	Plans that included a local planner in the planning process should include more land use-related mitigation strategies (Lyles, Berke, and Smith, 2014a).	Tested with both the original, three category data and as two category data. The two categories I used are planner "yes" or "no."
Consultant	Plans that include a consultant may include fewer land use strategies because they are less aware of local ordinances.	

All greening strategies	Plans that include greening strategies may include other types of land use mitigation strategies, specifically energy efficiency strategies.	
All energy efficiency strategies	Plans that include energy efficiency strategies may include other types of land use mitigation strategies, specifically greening strategies.	
	County Characteristics	
Region	Plans in regions typically associated with heat waves may use certain strategies more frequently than in other regions.	
State	The type of strategies included may vary based on state even within the same region.	
County population	Lyles, Berke, and Smith (2014b) identified population characteristics as important to the local planning context because size can influence planning capacity (p. 797 – 798). Dense urban areas deal with different hazard challenges than less dense urban areas (see Stone, 2012). Both reasons may mean that counties with larger populations or higher population densities use different mitigation strategies.	Tested as both the original, multi-category data and as two category data. The two categories I used are "population greater than 211,033" and "population of 211,033 or less"; I chose a population of 211,033 chosen because it is the median value.
Population density		Tested as both the original, multi-category data and as two category data. The two categories I used are "density greater than 293" and "density of 293 or less"; I chose a population density of 293 chosen because 292.6 is the median value.

I chose not to perform any bivariate analyses on the variables "All Cool Materials Strategies," "Heat-related cool materials strategies in implementation section," "Heat related greening strategies in implementation section," or "Heat related energy efficiency strategies in implementation section" because each of these variables had less than five plans each that included them.

Chapter 4: Are Counties Mitigating Heat Waves? An Analysis of Heat Sections and Heat-related Mitigation Strategies in Hazard Mitigation Plans

In this chapter, I analyze the results that help answer my three research questions: 1) what variables influence the comprehensiveness of a plan's heat section? 2) does a county's climatic region impact the strategies included in its hazard mitigation plan that could have heat wave mitigation co-benefits? and 3) what variables influence the comprehensiveness of a plan's heat section? In section 4.1, I outline the descriptive statistics for heat section rankings, heat-related mitigation strategies, and mitigation strategies with potential co-benefits. I found that most plans do have a heat section but most plans do not contain heat-related mitigation strategies. Because there were so few plans with heat-related mitigation strategies, I cannot reject the null hypothesis that regions do not influence the types of strategies included in plans. I also broadened my search to look for cool materials, greening, and energy efficiency strategies that are included in the plans but are not linked to heat wave mitigation. Nearly all of the plans, even those without heat sections, include at least one type of strategy that would likely have heat wave mitigation co-benefits.

In section 4.2, I used bivariate analyses to test which variables influence heat section ranking and which variables significantly influence the inclusion of various types of cool materials, greening, or energy efficiency strategies. I found that eight of the variables I collected, including county population statistics, geographical location of the county, and plan length, have a statistically significant relationship to heat section ranking. However, only one variable—drought word count—significantly influenced the type of greening strategies included. No variables significantly influenced the inclusion of any type of energy efficiency strategies.

4.1 Variation in heat section content and mitigation strategies

Through analyzing single variables, I found some variation in the heat section content and the mitigation strategies that plans included. I found that the majority of plans have a heat section. Most of these heat sections include information such as a heat wave severity rating, a heat wave probability rating, and a history of heat waves that indicate that the counties are aware of how significant an extreme heat event could be for their community. However, I found that a county's awareness of heat waves does not translate into more frequent heat wave mitigation strategies. Only five plans included cool materials, greening, or energy efficiency strategies specifically linked to heat wave mitigation. Yet 40 out of the 47 plans include at least one type of cool materials, greening, or energy efficiency strategy that the planners did not associate with heat wave mitigation. These strategies likely have heat wave mitigation co-benefits, and, therefore, should be considered when trying to understand how counties are mitigating heat waves.

To get these results, I analyzed single variables to identify patterns within the plans and the counties. In section 4.1.1, I outline the frequencies and some of the other descriptive statistics for the variables that I used to find the heat section ranking. In section 4.1.2, I provide the exact language of the heat-related land use mitigation actions from the six plans that included these strategies. In section 4.1.3, I analyze the cool materials, greening, and energy efficiency strategies included in the plans that could have heat wave mitigation co-benefits.

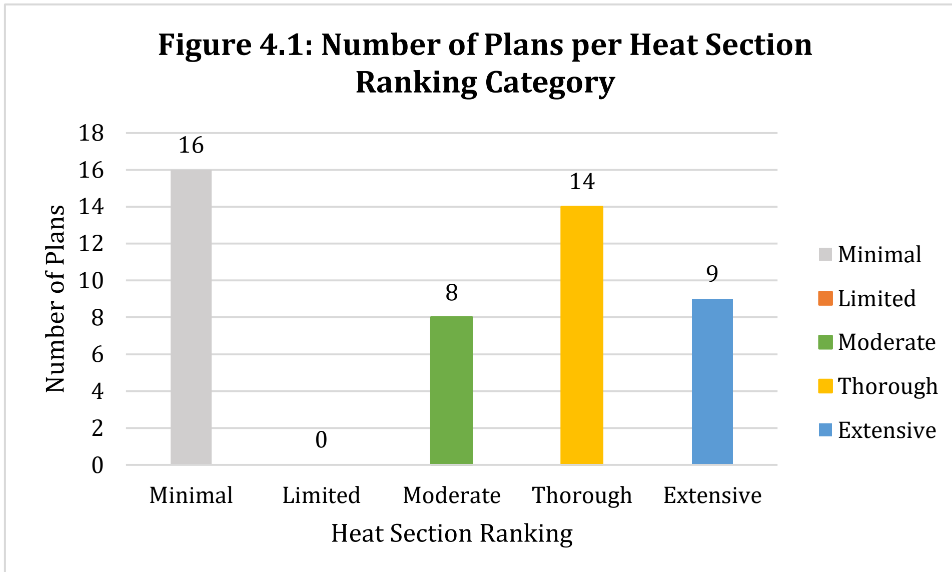
4.1.1 Heat section rankings. A majority of the plans have a section that establishes a fact-base for heat hazards. Understanding the type of the information included in heat sections in hazard mitigation plans helps us identify gaps in the knowledge local governments use to plan for heat waves. The first step in analyzing heat sections is identifying plans that have a heat section. Nearly 66% of the plans included a section on heat waves. Of the 31 plans that have a heat section, over half (17 plans or 54.8%) approached heat as a single hazard. Ten of the plans included heat waves in a section on extreme temperatures that included extreme cold. The remaining four plans combined heat with drought. Plan authors generally seem to recognize that heat is a significant enough hazard to consider on its own.

The second step in analyzing heat sections is to identify criteria that make up comprehensive sections. As explained in section 3.3.1 and figure 3.5, I developed a system to help me systematically rank the heat section in each plan. I used five variables that signify how seriously a county considers heat waves:

- Heat hazard severity rating included
- Heat hazard probability rating included
- Historical heat waves included
- Urban heat island referenced
- Length of heat wave section

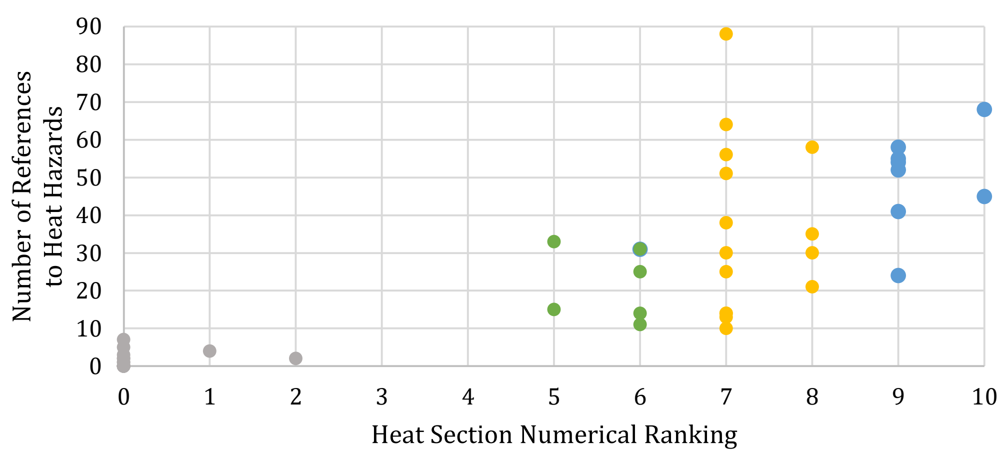
The five criteria ranking system had a total of 10 points possible. A score of 0 to 2 received a ranking category of "minimal." A score of 3 or 4 received a ranking category of "limited" (no plans received a score of 3 or 4). A score of 5 to 6 received a ranking category of "moderate". Plans with scores of 7 to 8 and 9 to 10 received ranking categories of "thorough" and "extensive," respectively.

Fourteen (29.8%) of the plans had a heat section I classified as “thorough”. Nine (19.1%) of the plans had an “extensive” heat section. Together, the extensive and thorough plans make up 48.9% of the plans. Eight (21.3%) of the plans contained a moderate heat section. The largest single group of plans (16 plans; 34%) received a “minimal” categorization because they did not include a heat section and, therefore, did not address extreme heat hazards in a meaningful way. Generally, the plans do contain a section that considers heat hazards in depth; of these plans, the majority have a thorough or extensive section. Figure 4.1 shows the number of plans per ranking category.



To ensure that the five criteria accurately reflect the plans, I conducted a Pearson's R test to examine the correlation between the numerical score each plan received and the heat hazard word count (which measures the number of times the phrases "extreme heat" and "heat wave" occur in the plan). When considering the correlation between the ranking and the heat hazard word count for all 47 plans, the r^2 value was only 0.21. However, the plan for Jackson County, MO, is an outlier because it has 445 references to heat hazards; Winnebago, IL, the plan with the next highest number of heat hazard references, had only 88 references. After removing the Jackson County outlier, the r^2 value increased to 0.61—a much stronger correlation (see Figure 4.2).

Figure 4.2: Heat Hazard Word Count and Heat Section Numerical Ranking
(Outlier Removed; n=46)



4.1.1.1 Extreme heat severity ratings. Nearly all of the plans that have a heat section also provided a heat hazards severity rating that estimates the potential impact or damage from heat on the community. Out of the 31 plans with heat sections, three plans did not rate the potential severity of a heat wave. Twenty-eight (28) of the plans included a rating of the potential impact. The largest number of plans, 11 or 35.5%, identified a heat wave as “guarded”. This rating typically takes into consideration impacts on human lives, the economy, and local infrastructure. Each plan uses different rating terminology, so I standardized the language (see Appendix Table 1).

4.1.1.2 Heat hazard probability rating. All of the plans with a heat hazard section included a hazard probability rating that estimates how likely it is for a community to experience the hazard. An equal number of plans (13) identified the probability of a heat wave as either “likely” or “highly likely.” Only five of the plans identified heat waves as unlikely. The heat hazard probability rating was usually estimated based on the frequency of past events. Each plan used different probability rating terminology, so I standardized the language (see Appendix Table 1).

4.1.1.3 Historical heat waves included. Plans that have a heat section always included a history of heat waves in the community. The Madison, IL, plan did not have a heat section but included some information on historical heat waves. In total, 32 plans referenced historical heat waves either within the county or regionally. Thirteen (13) plans provided historical information I classified as “robust” which meant it included counts of deaths attributable to heat waves. Nineteen (19) plans provided historical information I classified as “poor.” Because historical heat wave information varies by location with some going back to the early 1900s and some starting in the mid-1990s, the quality of the historical data varied widely (see Appendix Table 1).

4.1.2 Heat-related mitigation strategies. Few of the plans included mitigation actions specifically related to heat from the three land-use strategy categories: cool materials, greening, and energy efficiency strategies. Only 10.6% of the plans included any land-use mitigation actions specifically related to heat. Clearly there is a disconnect between counties and cities recognizing the threat of extreme heat and those same jurisdictions recognizing that they can take actions to help reduce the impact of heat waves before they strike. Figure 4.3 provides the exact wording used in the plan for each of the six strategies that identified heat as a one of the hazards mitigated by the strategy.

4.1.2.1 Heat-related cool materials strategies. Out of 47 plans, no plans included cool materials strategies meant to mitigate heat (or heat *and* other hazards) in the implementation section.

4.1.2.2 Heat-related greening strategies. Out of 47 plans, only two plans included greening strategies meant to mitigate heat (or heat *and* other hazards) in the implementation section. These plans covered Pima, AZ, and Denver, CO. In the Denver plan, the greening mitigation strategy is one that is already practiced by the city.

4.1.2.3 Heat-related energy efficiency strategies. Out of 47 plans, three plans included energy efficiency strategies related to heat in the implementation section—the most frequent strategy used. The strategies usually referred to retrofitting buildings and were often touted as a way to deal with all extreme weather events, including heat. These plans covered Adams, CO; Denver, CO; and Madison, IL.

Figure 4.3: Heat-Related Strategies in Implementation Sections

County	Strategy Category	Plan Action
Pima, AZ Population: 980,263 Density: 106.7 per sq. mile Ranking: Thorough	Greening	1. Landscape code amendment requiring vegetation adjustment in developed areas to reduce the heat island effect (p. 191).
Denver, CO Population: 600,158 Density: 3,922 per sq. mile Ranking: Extensive	Greening	1. Strategic tree replacement planting in anticipation of the Emerald Ash Borer to include trees that will be resilient to hazards, pests, and contribute to mitigation of stormwater runoff and urban heat island effects (p. 5-10).

		2. Implement enhanced tree management activities to mitigate damage caused by falling trees and limbs during wind and severe winter storm events (p. 5-32).
Adams, CO Population: 441,603 Density: 378.2 per sq. mile Ranking: Minimal	Energy Efficiency	1. Green Building—Promote the use of sustainable building and site design techniques that encourage use of renewable energy, support energy and water conservation, reduce the Heat Island Effect, and provide other benefits to the environment and community (p. 46).
Denver, CO Population: 600,158 Density: 3,922 per sq. mile Ranking: Extensive	Energy Efficiency	1. Emphasize energy saving measures: XCEL Energy has several measures they activate when extreme heat is forecasted. a. Use the nighttime to cool the transformers and get everything back to normal before the heat comes back during the day. b. Crews halt all maintenance work on the system during heat waves c. System design was built to withstand heavy use (defined as five days in a row of everyone in town blasting their air conditioning) (Appendix A, p. 3).
Madison, IL Population: 269,282 Density: 376.3 per sq. mile Ranking: Minimal	Energy Efficiency	1. Maintain and enforce building codes and update when revised codes have been published (p. 39).

4.1.3 Mitigation strategies with heat wave co-benefits. Because so few plans included heat-related mitigation strategies, I decided to analyze the implementation sections a second time to find any reference to cool materials, greening, or energy efficiency strategies that were used to mitigate other hazards. Mitigation efforts aimed at non-heat hazards have potential co-benefits for mitigating heat hazards even if counties have not made that connection yet. In the following three sections, I analyze how frequently each type of strategy appears in the plans. I also analyze the types of hazards that counties identify as being mitigated by these strategies.

4.1.3.1 Cool materials strategies. Cool Materials strategies were the least common strategies. Of these strategies, only decreasing impervious surfaces appeared in any of the plans. The strategy was only included in three (6%) of the plans—Winnebago, IL; Adams, CO; and Greene, MO. All three of the plans identified flooding as the main hazard mitigated by decreasing impervious surfaces. The Winnebago, IL, also recognized some mitigation benefits for droughts.

4.1.3.2 Greening strategies. Greening strategies were the most common type of strategy that could have heat wave mitigation co-benefits. 74% of the plans included some sort of greening strategy. Of these strategies, the most common was some variation of green infrastructure and open space. Seventeen (36%) of the plans identified green infrastructure/open space as an action the jurisdictions intended to implement. This shows that many communities are already mitigating heat waves with greening strategies even if they have not recognized their own efforts.

Planners could easily connect heat to the hazards already identified as mitigated by greening strategies. Flooding was the most frequently identified hazard with twenty-two (46.8%) of the 47 plans connecting greening strategies and flooding. Of the seventeen plans that identified green infrastructure and open space actions, sixteen (34.0%) connected these strategies with flooding. The second-most frequent mitigated hazard was severe weather, including tornadoes and winter storms. Fifteen (31.9%) of the 47 plans identified greening strategies as a way to mitigate severe weather.

4.1.3.3 Energy efficiency strategies. Energy efficiency strategies were the second-most common type of strategy with potential heat wave mitigation co-benefits. 45% of the plans listed some sort of action involving building code enforcement. Only 13% of the plans listed any other type of energy efficiency strategy. The most commonly mitigated hazard for energy efficiency strategies was severe storms with fifteen (31.9%) of the plans connecting energy efficiency strategies and severe storms. The presence of energy efficiency strategies suggests that communities may already be mitigating heat waves, if only by accident.

Figure 4.4: All Cool Materials, Greening, and Energy Efficiency Strategies with Co-benefits for Heat Mitigation		
Strategy	**Number of Plans**	**Percentage of Plans**
Cool Materials Strategies		
None	44	94%
Decrease impervious surfaces	3	6%
Increase surface reflectivity	0	0%
Other cool material strategies	0	0%
Greening Strategies		
None	12	26%
Native Vegetation/Landscape Ordinance Only	1 *Pima, AZ, was not included in this category because it only identified heat as the hazard mitigated by its landscape ordinance.	2.1%
Management (of trees and streams/development; includes maintenance) Only	1	2.1%
Tree/Vegetation Planting or Replacement (includes restoration) Only	2	4.3%
Removal/Trimming Only	5	10.6%
Participation in Tree City Only	2	4.3%
Green infrastructure/open space Only	6	12.8%
Multiple including green infrastructure/open space	11	23.4%
Multiple--all others	6	12.8%
Energy Efficiency Strategies		
None	21	44.7%
Building Weatherization/Retrofit only	3	6.4%
Building code enforcement only	19	40.4%
Green Buildings only	0 *The Adams, CO, plan is the only plan that	0%

	references green buildings. It also only identifies heat (specifically the Urban Heat Island) as the hazard mitigated by green buildings. As such, it is not included in this section.	
Multiple including building code	3	6.4%

4.2 Many variables influence heat section ranking; no variables influence mitigation strategies

I tested the relationship between three dependent variables—heat section rankings, greening strategies with co-benefits, and energy efficiency strategies with co-benefits—and multiple independent variables. I found that eight total variables have significant relationships with. Perhaps most importantly, there is significant variation in the heat sections between the six states and three regions. Thus, there is a correlation between heat section content and region. However, I found that mitigation strategies are not significantly influenced by region. Because heat wave mitigation strategies are not influenced by region, I cannot reject my null hypothesis. In fact, I found that only drought word count has a statistically significant relationship ($p < .05$) with greening strategies and no variables have a statistically significant relationship ($p < .05$) with energy efficiency strategies.

To find these results, I tested the relationship between my dependent variables—heat section rankings, all greening strategies, and all energy efficiency strategies—and the independent variables. In section 4.2.1, I provide the results of the ANOVA and means tables tests for the heat section rankings. In sections 4.2.2 and 4.2.3, I provide the results of the chi-square tests for the greening strategies and energy efficiency strategies, respectively. I separate the variables that are statistically significant from those that are not statistically significant in each section.

4.2.1 Correlations for heat section rankings. Four variables have a statistically significant correlation with the heat section ranking ($p < 0.05$). These variables and correlations are represented in Figure 4.5. One variable, climate change word count, did not have a statistically significant relationship with heat section ranking.

Figure 4.5: Significant Correlations for Heat Section Ranking

Variable	Pearson Correlation	Significance (2-tailed)
Drought Word Count	.392	.006
Plan Length	.383	.008
County Population	.363	.012
County Population Density	.397	.006

Interestingly, plans seem to link droughts and heat waves, suggesting a recognition of the interrelation between heat waves and other hazards. Not surprisingly, longer plans have more space to provide a fact base for heat hazards. The length of the plan may also help explain the connection between drought and heat waves—longer plans have more space to analyze all hazards, not just heat hazards. A multi-variate analysis should be conducted to determine if drought word count and plan length are independently significant. It is also clear from Figure 4.5 that population is closely related to the heat wave ranking. I further discuss my interpretation of these results in chapter 5.

4.2.2 ANOVA and means tables for heat section rankings. I tested the relationship between the heat section ranking and seven independent variables. Four variables significantly influence the heat section rankings. Three variables do not have statistically significant relationships with the heat section ranking.

4.2.2.1 Statistically significant variables. Four of the variables have a statistically significant relationship with the heat section ranking. These four variables are state, region, whether the plan covers multiple counties, and heat response strategies. In the following sections, I identify the ANOVA significance level for each variable and the mean and the standard deviation between the groups. In order to provide context for the mean, I also include the ranking category that each mean would fall into (extensive, thorough, moderate, or minimal).

4.2.2.1.a State. The mean of the heat section ranking for the six states varies greatly. There is a statistically significant difference in the mean ranking between the six states ($p<.05$). See Figure 4.6 for means and standard deviations. There is also significant difference between the states in each region, suggesting that there are factors that predict a county's heat section ranking better than geographical location.

Figure 4.6: ANOVA Report for States

Region	State	Mean (Ranking Category)	N	Std. Deviation
Midwest	Illinois	5.9 (moderate)	17	2.68
	Missouri	9.0 (extensive)	5	1.41
Great Plains	Kansas	5.8 (moderate)	4	3.86
	Montana	0.0 (minimal)	2	0.00
Southwest	Arizona	2.0 (minimal)	8	3.74
	Colorado	4.6 (limited)	11	3.80
	All	5.0 (moderate)	47	3.7

4.2.2.1.b Region. The heat section ranking means for the three regions vary less than the means between the states, but there is still a statistically significant difference between the means ($p < .05$). See Figure 4.7 for means and standard deviations. The Great Plains has the highest mean, with an equivalent heat section ranking category of moderate. The means for the Midwest and the Southwest are almost equal.

Figure 4.7: ANOVA Report for Regions

Region	Mean (Ranking Category)	N	Std. Deviation
Great Plains	6.6 (moderate)	22	2.75
Midwest	3.8 (limited)	6	4.22
Southwest	3.5 (limited)	19	3.91

4.2.2.1.c Multi-county plan. There is a statistically significant difference in the mean ranking for the heat section between plans that cover multiple counties versus plans that cover one county ($p < .05$). The mean for multi-county plans ($n = 7$) is 7.6 (ranking category: thorough) with a standard deviation of 1.90. The mean for single-county plans ($n = 40$) is 4.6 (ranking category: moderate) with a standard deviation of 3.78. Plans that cover larger areas seem to have more resources for adequately addressing all types of hazards.

4.2.2.1.d Heat response strategies. There is a statistically significant difference in the mean ranking for the heat section between plans that included heat response strategies versus plans that did not ($p < .05$). The mean for plans that included heat response strategies ($n = 26$) is 6.1 (ranking category: moderate) with a standard deviation of 3.56. The mean for plans that did not include heat response strategies ($n = 21$) is 3.7 with a standard deviation of 3.5 (ranking category: moderate). Not surprisingly, plans that include efforts to respond to heat waves also provide more comprehensive heat wave fact bases.

4.2.2.2 Variables that are not statistically significant. Three of the variables I tested do not have statistically significant relationships with the heat ranking section. These variables are:

- Planner
- Consultant
- County voting

4.2.3. Chi-square for greening strategies. I tested the relationship between the presence of any greening strategy in the implementation section and eleven independent variables. Only one variable, drought word count, was statistically significant. This suggests that any type of community may have opportunities to incorporate greening strategies into their plans to mitigate heat waves and other hazards. If the strategies are already included, any type of community could connect current mitigation actions to heat wave mitigation.

4.2.3.1 Statistically significant variables. One variable—drought word count—had a statistically significant relationship ($p < .05$) to the presence of greening strategies in the implementation section of plans. The significance level is .036. The Phi value is .305, indicating that there is a weak to moderate relationship between the drought word count and the presence of greening strategies. Drought word count was also statistically significant for the heat section ranking, suggesting that there is a link between mitigation opportunities for heat waves and how well other hazards are covered in the plan.

4.2.3.2 Variables that are not statistically significant. Five of the variables did not have a statistically significant relationship to the presence of greening strategies ($p > .05$). These variables are:

- Plan length
- Consultant
- County population
- County population density
- All energy efficiency strategies

4.2.3.1 Variables that did not meet Chi-square assumptions. Five variables did not meet the basic assumption for Chi-square that all expected counts are five (5) or greater. These variables are:

- State
- Region
- Multi-county plan
- Climate change in plan
- Planner

4.2.4 Chi-square for energy efficiency strategies. I tested the relationship between the presence of any energy efficiency strategy in the implementation section and eleven independent variables. The variables I tested either did not meet the necessary assumptions for Chi-square tests or were not statistically significant. Similar to the results for greening strategies, any community could incorporate energy efficiency strategies into their plans to mitigate heat waves and other hazards.

4.2.4.1 Variables that did not meet Chi-square assumptions. Three variables did not meet the basic assumption for Chi-square that all expected counts are five (5) or greater. These variables are:

- State
- Region
- Multi-county plan

4.2.4.2 Variables that are not statistically significant. None of the remaining eight variables had a statistically significant relationship the presence of energy efficiency strategies ($p > .05$). These variables are:

- Climate change referenced in plan
- Drought word count
- Plan length
- Planner
- Consultant
- County population
- Population density
- All greening strategies

Chapter 5: The Current State of Heat Wave Mitigation in Hazard Mitigation Plans

In the following chapter, I interpret the results I outlined in chapter 4 to help answer my three research questions: 1) what variables are associated with the comprehensiveness of a plan's heat section? 2) does a county's climatic region impact the strategies included in its hazard mitigation plan that could have heat wave mitigation co-benefits? and 3) what variables influence the comprehensiveness of a plan's heat section? In answer to question 1, I found that many of the variables I collected have a relationship with the heat section ranking, suggesting that there are significant variations in how counties in different states and regions approach heat hazards in their plans.

In answer to question 2, however, I found that region does not have a significant relationship with the types of heat wave mitigation strategies or strategies with heat wave mitigation co-benefits that a plan includes. In fact, I found that only one of the variables I collected, drought word count, has a positive relationship with the inclusion of greening strategies used to mitigate any hazards. None of the variables were associated with the inclusion of energy efficiency strategies with potential heat wave mitigation co-benefits. The lack of a significant relationship between the strategies and the independent variables is likely due to 1) the small sample size and 2) not including the correct variables. Research limitations and suggestions for future research are further explained in section 5.1.3.

I conclude the chapter and my thesis by reviewing the full thesis. I then provide some suggestions for training practitioners and for future research. I also outline the contributions my research makes to the topic of heat hazard mitigation.

5.1 Heat Section Ranking and Heat Mitigation Strategies Findings

I separated the discussion of my findings into two sections based on my research questions. First, I interpret the results of the univariate and bivariate analyses I calculated for the heat section ranking. Second, I interpret the results of the univariate and bivariate analyses I performed on the inclusion of the three heat wave mitigation strategies—cool materials strategies, greening strategies, and energy efficiency strategies—in the plans.

5.1.1 Heat section ranking. A majority of the plans have a heat section, although the comprehensiveness of these sections varies greatly. I was able to identify eight variables that help predict the heat section comprehensiveness. The presence of heat sections in the plans shows that most counties consider extreme heat a hazard of concern and at least realize that heat hazards should be included in a hazard mitigation plan. Most of the plans also deal with heat separately from other hazards. This suggests that counties realize heat is a complex enough hazard to be considered on its own. Of the plans that include heat sections, 74.2% received a ranking of "thorough" or "extensive." This suggests that when counties recognize that heat waves could be a problem in their communities, they include a comprehensive section about heat hazards.

5.1.1.1 State and region. There is significant variation in the mean ranking between the states. Both Montana and Arizona have a mean ranking that is equivalent to a "minimal" categorization. Colorado's mean ranking is equivalent to a "limited" categorization. Illinois and Kansas have mean rankings that are equivalent to a "moderate" categorization. Only Missouri has a mean ranking that is equivalent to an "extensive" ranking categorization. There is also a significant variation in the mean ranking between the three regions. The difference is most stark between the Great Plains and the other two regions, Midwest and Southwest. The Great Plains has a mean of 6.6, a "moderate" categorization. This is nearly three points higher than the mean ranking score for either the Midwest (mean of 3.8) and the Southwest (mean of 3.5), both of which would be categorized as "limited."

The difference between the states and the regions suggest that areas historically associated with heat waves are more likely to include them in hazard mitigation plans. The Midwest, with high humidity and some of the worst heat waves in the nation's history, has the highest mean heat section ranking (Sheridan, 2006, p. 3). The Southwest, historically not associated with heat waves, has the lowest mean heat section ranking. This is consistent with Zahran, Brody, Vedlitz, Grover, and Miller's (2008) finding that the number of people killed by extreme weather events (in other words, an area's experience with a hazard) influenced the community's willingness to commit to a climate protection campaign (p. 544).

Given the linkage between heat section comprehensiveness and regions with historic heat waves, it is somewhat surprising that Illinois, home to the Chicago heat wave of 1995—one of the worst heat waves in US history (Klinenberg, 2002)—scored 3 points lower than Missouri, the state with the highest mean ranking for heat sections, and only 0.1 points higher than Kansas, the state with the third highest mean ranking. Some of the difference is likely due to the larger number of plans obtained from Illinois (n=17 or 36.2% of the total plans) versus Missouri (n=5 or 10.6% of the total plans). The number of plans, however, is not the only variable that may be influencing Missouri's higher mean ranking. As discussed in section 5.1.1.5, the population size and density of a county have a positive relationship with the heat section ranking (other researchers also considered population an important part of hazard mitigation plan evaluation; see Lyles, Berke, and Smith, 2014b). The average county population for the 17 Illinois counties is 308,659 and the average county population density is 618.16 people per square mile. In comparison, the average county population for the five Missouri counties is 445,666 and the average county population density is 782.24, both considerably larger than the Illinois averages.

5.1.1.2 Multi-county plan. The statistically significant relationship between multi-county plans and heat section ranking suggests that when communities approach hazard mitigation plans regionally, the plans have more comprehensive heat sections. This finding may be related to larger areas having more resources for planning (see Lyles, Berke, and Smith, 2014a, p. 92). The limited number of multi-county plans (n=7) in this research constrains the generalizability of this finding. A future research project could compare multi-county with single-county plans to determine if this finding holds up over a larger sample size. If this finding does hold true, state and federal agencies should consider requiring more regional plans.

5.1.1.3 Heat response strategies. There is a positive relationship between a plan's heat section ranking and whether the plan included heat response strategies such as education and cooling centers in the implementation section. It is not surprising that plans that included heat response strategies should have a higher heat section ranking. If planners identify ways to respond to heat, then they have likely identified heat as a hazard of concern. The relationship between plans with comprehensive heat sections and heat response strategies reflects the increase in awareness about heat waves and responding to heat waves that multiple researchers have identified (Bernard and McGeehin, 2004; Lowe, Ebi, & Forsberg, 2011). The relationship also suggests that there is a foundation to build on for helping planners understand that they can *mitigate* as well as *respond to* heat waves (Stone, 2012).

5.1.1.4 County population and population density. Both county population and county population density have a positive relationship with heat section ranking. Density is often associated with a stronger urban heat island effect (Stone, 2012). However, Stone, Hass, and Frumkin (2010) found that the rate of increase in extreme heat events (EHEs) in areas of high urban sprawl (less dense urban areas) was more than double the rate of increase in the densest urban areas (p. 1425). My findings suggest that less dense urban areas may not be as aware of the risk from EHEs as are denser urban areas.

5.1.1.5 Drought word count and plan length. Drought word count has the second strongest correlation with heat section ranking. This relationship suggests that the more a community engages with one type of hazard, the more likely they are to engage with another. The relationship between hazards may be found only between those hazards that are considered related to each other, such as drought and heat waves. On the other hand, the relationship between hazards may have more to do with the length of the plan than with the specific type of hazards. In the case of drought and heat waves, the number of references to drought is likely associated with the length of the plan as the longer a plan is the more space there is for covering all hazards. This is further confirmed by the significant correlation between plan length and the heat section ranking. In future research, a multi-variate analysis should be done to ensure that both variables are, in fact, significant. It is also important to note that a longer plan does not necessarily mean a better plan. In some cases, plan length could make a plan more cumbersome to use and less likely to be implemented.

5.1.2 Heat wave mitigation strategies. Few plans included cool materials, greening, or energy efficiency strategies specifically related to mitigating heat. Because of the small number of plans with heat-related mitigation strategies, I could not test the impact of region on the types of strategies included. Thus, I cannot reject the null hypothesis that region has no impact on the inclusion of heat wave mitigation strategies.

A majority of the plans included cool materials, greening, or energy efficiency strategies that could have heat wave mitigation co-benefits. Region still has no relationship with the type of strategies included. This suggests that areas in the Southwest may be relying too much on greening strategies (the most common type of co-benefit strategy included in the plans) without taking into consideration the water costs of these strategies (Gober et al, 2009; Harlan, Brazel, Prashad, Stefanov, and Larsen, 2006). There is little or no relationship between the types of strategies included in the plans and the independent variables I tested.

There seems to be a disconnect between counties recognizing the threat of extreme heat and those same counties recognizing that they can take actions to help reduce the impact of heat waves before they occur. Only five plans included any heat-related mitigation strategies. In comparison, 26 plans included heat response strategies and 41 included cool materials, greening, or energy efficiency strategies with potential heat wave mitigation co-benefits.

The lack of heat-related mitigation strategies in hazard mitigation plans is one of the most important findings in my thesis. This finding supports Stone's (2012) research that local jurisdictions have not yet realized that climate change is happening at the local as well as the global scale. It also matches Lyles, Berke, and Godschalk's (2014a) findings that hazard mitigation plans underutilize land use mitigation strategies despite the efficacy of mitigating hazards through land use. In the following sections, I discuss the implications of the three categories of strategies. The heat-related strategies and the co-benefit strategies are discussed in the same section.

5.1.2.1 Cool materials strategies. Only three plans included any cool materials strategies. These plans all identified the flood mitigation benefits of decreasing impervious surfaces. The lack of cool materials strategies may be explained in two ways. First, they are the strategies most closely tied to land use and, therefore, least likely to be under the control of emergency management departments. Second, two of the cool materials strategies—lighter colored roofs and lighter colored paving materials—also have few easily recognizable co-benefits for mitigating other hazards. The lack of co-benefits along with the emergency management department's lack of jurisdiction may reduce their likelihood for being included in hazard mitigation plans.

5.1.2.2 Greening strategies. Heat-related greening strategies are the second most common type of heat-related land-use strategies included in the plans. Two plans included greening strategies for mitigating heat waves. Both plans are in the Southwest region, which is somewhat surprising considering the region's low number of plans with heat sections (only nine of the nineteen plans from the Southwest include a heat section). This suggests that heat waves might be a newly recognized hazard for the Southwest, so plan authors may be more aware of mitigation options. However, greening strategies, which rely on vegetation (and, therefore, water), may not be the best strategies for the most arid region of the country (Gober et al, 2009; Harlan, Brazel, Prashad, Stefanov, and Larsen, 2006). Although greening strategies have the greatest impact on reducing the urban heat island effect and on mitigating extreme heat events, practitioners must carefully consider the tradeoffs of using water to cool arid cities.

Greening strategies are the most common category of mitigation that could have heat wave mitigation co-benefits. Nearly three-quarters of the plans identified a greening strategy, with the most common being green infrastructure or open space. Many plans identified multiple greening strategies. The prevalence of these strategies is likely explained by the more commonly understood benefits of planting trees, having parks, and so on. It is also likely that many jurisdictions have a Parks and Recreation department that is already charged with maintaining vegetation and open space. Thus, it would be more likely that those involved in hazard mitigation planning could identify greening strategies with the knowledge that the strategies are already being implemented.

5.1.2.3 Energy efficiency strategies. Heat-related energy efficiency strategies are the most common type of heat-related land-use strategies included in the plans. Three plans specifically link energy efficiency efforts to heat reduction. In both the Adams, CO, and the Madison, IL, plans, the strategy focuses on encouraging energy efficiency in future buildings. In Denver, CO, the energy efficiency strategy focuses on efforts taken by the local energy provider. None of the strategies target energy efficiency in current buildings, so they are missing an important part of reducing waste heat.

Energy efficiency strategies were the least clear of the co-benefit strategies. Although 45% of the plans listed some sort of action involving building code enforcement, most of the actions did not explicitly cite energy efficiency as one of the benefits or purposes of enforcing the codes. Most plans, however, did indicate that the codes to be enforced were the numerous versions of the International Building Codes, including the International Energy Conservation Code. I assumed that energy efficiency—and the cooling benefits of cutting down on waste heat—would be a byproduct of building code enforcement.

5.1.2.4 Drought word count. Of the eleven variables I tested for both Greening Strategies with Co-benefits and Energy Efficiency Strategies with Co-benefits, only one—drought word count—had a positive relationship—and only for Greening Strategies. The relationship between drought word count and co-benefit strategies suggests that a high amount of awareness about certain hazards leads to the inclusion of the most land-use mitigation strategies. A similar test should be done for flooding and severe storms to see if the significance holds across hazards.

The lack of relationship between county characteristics, plan characteristics, and heat wave data in plans means that there is not one type of community that has an advantage over another in receiving the heat wave mitigation co-benefits of various mitigation actions. There are likely mitigation strategies already planned that could have co-benefits for heat wave mitigation that the county could take advantage of no matter how the plan was developed or what the county population is. The lack of significant variables may also mean that I missed some important variables, including county median income which Zahran, Brody, Vedlitz, Grover, and Miller (2008) found significantly influenced a community's voluntary involvement in the Cities for Climate Protection campaign. A future research project should include county median income as this often indicates how many resources a county has for implementation of the plan mitigation actions.

5.1.2.5 Planners included in planning process. The most surprising result from my research is that the involvement of a planner does not have a significant relationship with any of the dependent variables. Lyles, Berke, and Godschalk (2014b) found that the participation of local planners in the hazard mitigation planning process significantly impacted the inclusion of land-use mitigation strategies in hazard mitigation plans. The lack of a statistically significant relationship between planners and heat wave mitigation strategies may be explained by the type of planner involved as the relationship between land use mitigation strategies and planners found by Lyles, Berke, and Godschalk (2014b) only applied to local planners. However, 20 of the 32 plans (62.5%) that included planners had planning representatives from the county, the cities within the county, or both. Thus, it is unlikely that the lack of a significant relationship is due to a lack of inclusion of local planners.

Instead, the finding that the inclusion of heat wave mitigation strategies or the inclusion of mitigation strategies with heat wave co-benefits is not associated with the involvement of planners in the planning process has important implications for practitioners and professional development. First, planners need to be taught that heat waves can be mitigated—not just responded to—using land use strategies. Second, the work that Lyles, Berke, and Godschalk (2014b) did focused on coastal communities that are dealing with the most evident hazard associated with climate change—sea level rise. My findings suggest that planners in the interior US may not have as much understanding about or as many resources for handling the temperature changes that will impact their communities due to climate change. As such, planners in the interior US need to be better prepared about the implications of climate change, particularly heat waves, for their communities. This may also have to do with fewer local planners being involved.

5.1.3 Research limitations and suggestions. The research described in this thesis only includes descriptive and bivariate analyses. Some of these analyses were limited by the small number of plans included in the study. A future research project might expand the number of plans by including counties in the population range 100,000 to 1,000,000 from all of the states in the three climatic regions considered in this study. Multivariate analyses also need to be calculated on the eight variables that have significant relationships with heat section comprehensiveness to ensure that these variables are independent of each other. Other research suggestions include intrastate analyses. For example, why did some counties in Arizona rate heat hazards as "highly likely" while most counties did not include a section about heat hazards?

Two limitations of this study were that I did not include a variable that represents county socioeconomic status and resources or the state planning context. Other climate adaptation and hazard mitigation plan research has found that both socioeconomic variables and state planning context are significant in predicting adaptation efforts and the inclusion of land use mitigation strategies (Lyles, Berke, and Smith, 2014a; Lyles, Berke, and Smith, 2014b; Zahran, Brody, Vedlitz, Grover, and Miller, 2008). A socioeconomic variable such as median income should be included in future research. The state planning context should be determined using a similar method as Lyles, Berke, and Smith used (2014a; 2014b).

5.2 Conclusion

I started my research wanting to answer the question of how heat wave mitigation strategies differ by climatic region. What I found, however, is that most counties have not yet transitioned from responding to heat waves to mitigating them. This finding led to a new research question—how comprehensive are heat sections in county hazard mitigation plans?—and to a revision of my original question—are counties incorporating mitigation strategies for other hazards that could have co-benefits for heat waves?

As outlined in chapter 2, heat waves are an important hazard to study because they are one of the hazards that will increase for all areas of the US due to climate change (Melillo, Richmond, and Yohe, 2014). Heat wave frequency and intensity is already increasing for many urban areas due to local climate change, also known as the Urban Heat Island (UHI) effect or the phenomenon that cities are warming faster than rural areas that surround them (Stone, 2007; Stone, 2012). Heat waves have also killed more people in the US than any other weather related hazard, including flooding (NWS, 2016). For these reasons, it is important that communities know how to mitigate heat hazards using land use strategies. Researchers who study the UHI effect and heat waves have identified three categories of land use strategies that can help communities reduce the severity of heat waves before they occur (Stone, 2012; Stone, Vargo, Liu, Hu, & Russell, 2013; Urban Climate Lab, 2016). These heat wave mitigation strategy categories are cool materials, greening, and energy efficiency strategies.

I used a cross-sectional, multi-state approach to analyze county hazard mitigation plans (HMP) from six US states. Other researchers have used similar methodology to evaluate plan quality and hazard mitigation plans (Lyles, Berke, and Smith, 2014a; Lyles, Berke, and Smith, 2014b). I used county-level HMPs because nearly every county in the US has a plan in order to be eligible for federal disaster funds. I developed a three-step process to generate a representative sample of counties from the interior US. 1) I determined the climatic regions and the climatic sub-regions. 2) I randomly selected the states from the sub-regions. 3) I selected the counties based on population (over 100,000 and under 1,000,000). I ended up with 47 county HMPs.

I then collected three categories of data: county characteristics, plan characteristics, and heat wave data. I used a coding approach similar to coding used in other plan evaluation studies (see Lyles, Berke, and Smith, 2014a, p. 92). I also developed a systematic approach for analyzing the heat sections in each plan. Although I was the only coder, I read through each plan three times and updated my data if I found discrepancies. I analyzed my data using descriptive statistics, Pearson's R correlations, ANOVA tests, means tables, and Chi-square tests.

Through the data analysis, I found that over 60% of the plans included a heat section. This suggests that most counties are aware that heat hazards are a problem. However, I also found that only 10.6% of the plans included cool materials, greening, or energy efficiency strategies related to heat wave mitigation. Clearly, hazard mitigation planners have not yet realized that "changing the weather in cities [is] a viable policy option" (Stone, 2012, p. 103). The small number of plans with heat-related mitigation strategies means that I cannot reject the null hypothesis of region having no impact on heat wave mitigation strategies. There is no relation between strategies included and region even when the analysis is expanded to include cool materials, greening, or energy efficiency strategies with potential heat wave mitigation co-benefits. Region does, however, have a significant relationship with the comprehensiveness of heat sections. It is clear that counties located in regions that are historically associated with heat waves and counties that are more urbanized provide a more comprehensive description of the potential threat of heat hazards. Only one variable had a significant relationship with the co-benefit strategies included. This suggests that either the small sample size limited the relationships or I did not include the correct variables.

My research contributes to the literature on heat wave and hazard mitigation planning in two ways. First, it focuses on hazard mitigation plans from the interior US, an area underrepresented in both heat wave and climate change mitigation research. Second, it focuses on one type of hazard—heat waves or extreme heat events—an approach that has never been taken in hazard mitigation plan evaluations. My research also highlights some important suggestions for planners and researchers. Planners in the interior US need to be made more aware of the threats climate change poses to their communities, especially in the form of extreme heat events. Planners also need to be instructed on the significant impacts land use choices have on the frequency and intensity of heat waves and on the best types of heat wave mitigation strategies for their communities.

References

Berke, P., Backhurst, M., Day, M., Ericksen, N., Laurian, L., Crawford, J., & Dixon, J. (2006). What makes plan implementation successful? An evaluation of local plans and implementation practices in New Zealand. Environment and Planning B: Planning and Design, 33(4), 581-600.

Berke, P. R., & Conroy, M. M. (2000). Are we planning for sustainable development? An evaluation of 30 comprehensive plans. Journal of the American planning association, 66(1), 21-33.

Berke, P., & Godschalk, D. (2009). Searching for the good plan: A meta-analysis of plan quality studies. CPL bibliography, 23(3), 227-240.

Berke, P., Smith, G., & Lyles, W. (2012). Planning for resiliency: Evaluation of state hazard mitigation plans under the disaster mitigation act. Natural Hazards Review, 13(2), 139-149.

Bernard, S. M., & McGeehin, M. A. (2004). Municipal heat wave response plans. American Journal of Public Health, 94(9), 1520-1522.

City of Melbourne, Australia (2009). City of Melbourne climate change adaptation strategy.

Gaffen, D. J., & Ross, R. J. (1998). Increased summertime heat stress in the US. Nature, 396(6711), 529-530.

Gober, P., Brazel, A., Quay, R., Myint, S., Grossman-Clarke, S., Miller, A., & Rossi, S. (2009). Using watered landscapes to manipulate urban heat island effects: how much water will it take to cool Phoenix? Journal of the American Planning Association, 76(1), 109-121.

Godschalk, D. R. (2003). Urban hazard mitigation: creating resilient cities. Natural hazards review, 4(3), 136-143.

Habeeb, D., Vargo, J., & Stone Jr, B. (2015). Rising heat wave trends in large US cities. Natural Hazards, 76(3), 1651-1665.

Harlan, S. L., Brazel, A. J., Prashad, L., Stefanov, W. L., & Larsen, L. (2006). Neighborhood microclimates and vulnerability to heat stress. Social science & medicine, 63(11), 2847-2863.

Hoerling, M. (2012, December 11). Meteorological March madness 2012. Retrieved from https://www.esrl.noaa.gov/psd/csi/events/2012/marchheatwave/index.html.

Klinenberg, E. (2002). Heat wave: A social autopsy of disaster in Chicago. University of Chicago Press.

Klosterman, R. E. (1985). Arguments for and against planning. Town planning review, 56(1), 5.

Lowe, D., Ebi, K. L., & Forsberg, B. (2011). Heatwave early warning systems and adaptation advice to reduce human health consequences of heatwaves. International journal of environmental research and public health, 8(12), 4623-4648.

Lyles, W., Berke, P., & Smith, G. (2014a). A comparison of local hazard mitigation plan quality in six states, USA. Landscape and urban planning, 122, 89-99.

Lyles, L. W., Berke, P., & Smith, G. (2014b). Do planners matter? Examining factors driving incorporation of land use approaches into hazard mitigation plans. Journal of environmental planning and management, 57(5), 792-811.

Melillo, J. M., Richmond, T. T., & Yohe, G. (2014). Climate change impacts in the United States. Third National Climate Assessment. doi:10.7930/J0Z31WJ2.

Rojc, P. (2016, October 2). Tamping down urban heat islands. *Planetizen*. Retrieved from https://www.planetizen.com/node/88908/tamping-down-urban-heat-islands.

Schlossberg, T. (2016, August 9). How bad is your air-conditioner for the planet? *New York Times.* Retrieved from https://www.nytimes.com/2016/08/10/science/air-conditioner-global-warming.html?_r=0.

Semenza, J. C., Rubin, C. H., Falter, K. H., Selanikio, J. D., Flanders, W. D., Howe, H. L., & Wilhelm, J. L. (1996). Heat-related deaths during the July 1995 heat wave in Chicago. New England journal of medicine, 335(2), 84-90.

Sheridan, S. C. (2007). A survey of public perception and response to heat warnings across four North American cities: an evaluation of municipal effectiveness. International Journal of Biometeorology, 52(1), 3-15.

Steinberg, T. (2006). Acts of God: The unnatural history of natural disaster in America. Oxford University Press.

Stone, B. (2007). Urban and rural temperature trends in proximity to large US cities: 1951–2000. International Journal of Climatology, 27(13), 1801-1807.

Stone Jr, B. (2012). The city and the coming climate: Climate change in the places we live. Cambridge University Press.

Stone, B., Hess, J. J., & Frumkin, H. (2010). Urban form and extreme heat events: are sprawling cities more vulnerable to climate change than compact cities. *Environmental health perspectives*, *118*(10), 1425-1428.

Stone, B., Vargo, J., & Habeeb, D. (2012). Managing climate change in cities: will climate action plans work?. Landscape and Urban Planning, 107(3), 263-271.

Stone Jr, B., Vargo, J., Liu, P., Hu, Y., & Russell, A. (2013). Climate change adaptation through urban heat management in Atlanta, Georgia. Environmental science & technology, 47(14), 7780-7786.

Williams, J. (2017, May 5). Beating the heat (island effect) with the Japanese tradition of uchimizu. *Planetizen*. Retrieved from https://www.planetizen.com/node/92571/beating-heat-island-effect-japanese-tradition-uchimizu.

United Nations Environment (n.d.). Climate change: Mitigation. Retrieved from http://www.unep.org/climatechange/mitigation.

Urban Climate Lab of the Georgia Institute of Technology (2016, April). Louisville urban heat management study.

U.S. Department of Homeland Security Office of the Inspector General (2012). Survey of Hazard Mitigation Planning. OIG-12-109. Retrieved from https://www.oig.dhs.gov/assets/Mgmt/2012/OIG_12-109_Aug12.pdf.

U. S. Environmental Protection Agency (EPA) (n.d.). Heat waves. *PDF brochure*. Retrieved from https://www3.epa.gov/climatechange/pdfs/print_heat-waves.pdf.

U.S. EPA (2016a, August). Climate change indicators: High and low temperatures. *Figure 2*. Retrieved from https://www.epa.gov/climate-indicators/climate-change-indicators-high-and-low-temperatures#6.

U.S. EPA (2016b, December 17). Climate change indicators: Heat-related deaths. Retrieved from https://www.epa.gov/climate-indicators/climate-change-indicators-heat-related-deaths.

U.S. Federal Emergency Management Agency (FEMA) (2013, September 26). Disaster Mitigation Act of 2000. Retrieved from https://www.fema.gov/media-library/assets/documents/4596.

U.S. FEMA (2017, February 2). Hazard mitigation planning. Retrieved from https://www.fema.gov/hazard-mitigation-planning.

U.S. FEMA (2016, December 23). Hazard mitigation planning process. Retrieved from https://www.fema.gov/hazard-mitigation-planning-process.

U.S. FEMA (n.d.). Natural hazards: Part 2. Retrieved from https://www.fema.gov/media-library-data/20130726-1549-20490-4629/natural_hazards_1.pdf.

U.S. National Weather Service (NWS) (n.d.a). Heat index. *Graph*. Retrieved from http://www.nws.noaa.gov/om/heat/heat_index.shtml.

U.S. National Weather Service (NWS) (n.d.b). Heat wave: A major summer killer (brochure). Retrieved from http://www.nws.noaa.gov/om/brochures/heatwave.pdf.

U.S. National Weather Service (NWS) (2016, April 6). Natural hazard statistics: Weather fatalities. *Graph*. Retrieved from http://www.nws.noaa.gov/om/hazstats.shtml.

Appendix

Table 1: Variables			
Variable Name	**Description and Coding**	**Measures of Central Tendency**	**Measures of Dispersion**
Plan Characteristics			
Multi-county Plan	Whether plan covers multiple counties 0 - No 1 - Yes	Mode: No	N/A
Plan length	Number of pages in the plan	Mean: 353.81 Median: 280 Mode: n/a	Min: 109 Max: 1784 IQR: 185.5 SD: 269.11
Year	Year plan was written/adopted	Median: 2012 Mode: 2015	Min: 2005 Max: 2016 IQR: 5
Heat Wave Data			
Heat Section Number of Pages	Number of pages in the heat section	Mean: 3.29 Median: 2.00 Mode: 0	Min: 0 Max: 18 IQR: 5.5 SD: 3.85
Heat Section Approach	Whether the county separated the heat section from all other hazards or combined it with a related hazard (cold or drought) 0 - Not present 1 - Heat Only 2 - Extreme Temperatures 3 - Heat and Drought	Mode: Not present and Heat Only	N/A
Heat Hazard Word Count	Frequency of heat hazards ("extreme heat" and "heat wave") in entire plan	Mean: 33.53 Median: 21 Mode: 0	Min: 0 Max: 445 IQR: 40.5 SD: 65.53
Climate Change Word Count	Frequency of “climate change” in entire plan	Mean: 4.77 Median: Mode: 0	Min: 0 Max: 97 IQR: 1 SD: 15.68
Drought Word Count	Frequency of “drought” in entire plan	Mean: 125.85 Median: 100 Mode: 62	Min: 2 Max: 762 IQR: 128.5 SD: 121.39

UHI explained	Whether counties explained the concept of urban heat islands 0 - No 1 - Yes, in other part of plan 2 - Yes, in heat section	Mode: No	N/A
History of heat waves provided	Whether the history of heat waves was included 0 - No 1 - Yes (no death count provided) 2 - Yes, High Quality (death count provided)	Mode: Yes, High Quality	N/A
Heat Hazard severity rating	Identification of how severe a heat hazard is expected to be in the planning area 0 - Not provided 1 - Low (Identified in plans as low or limited) 2 - Guarded (Identified in plans as guarded, moderate, or medium) 3 - Elevated (Identified in plans as elevated or high) 4 - Critical (Identified in plans as critical or highest)	Median: Low Mode: Not provided	Min: 0 Max: 4 IQR: 2
Probability Rating	Identification of how probable a heat wave is in the planning area 0 - Not provided 1 - Unlikely (Identified in plans as low or 15% or lower chance) 2 - Likely (Identified in plans as likely, over 15% but under 44% chance, medium, or elevated) 3 - Highly Likely (Identified in plans as highly likely, high, or over 45% chance)	Median: Likely Mode: Not provided	Min: 0 Max: 3 IQR: 3
Planner involved	Whether a planner from the government (not from a consulting firm) was involved in the planning process; emergency management planners were not included in this variable 0 - No 1 - Yes	Mode: Yes	N/A
Consultant involved	Whether a consultant assisted in writing the plan 0 - No 1 - Yes	Mode: Yes	N/A
Heat-related "cool materials strategies" in	Whether strategies that relate to cooling, impervious/pervious surfaces, or roof surfaces are included	Mode: No	N/A

implementation section	in implementation AND are related back to heat hazard 0 - No 1 - Yes		
Heat related "greening strategies" in implementation section	Whether strategies that relate to vegetation, trees, forest, or landscape are included in implementation AND are related back to heat hazard 0 - No 1 - Yes	Mode: No	N/A
Heat related "energy efficiency strategies" in implementation section	Whether strategies that relate to energy, weatherization, or retrofit are included in implementation AND are related back to heat hazard 0 - No 1 - Yes	Mode: No	N/A
All Cool Materials Strategies Standardized	Cool material strategies used to mitigate any hazard; potential for making links to heat mitigation (multiple mitigation strategies collapsed into category "multiple") 0 - None 1 - Decrease impervious surfaces 2 - Increase surface reflectivity 3 - Cooling 4 - Multiple	Mode: No	N/A
Hazards Mitigated by Cool Materials, Greening, and Energy Efficiency Strategies	Hazards the plan identifies as being mitigated by cool materials strategies (multiple hazards mitigated collapsed into category "multiple") 0 - None 1 - Flood 2 - Drought 3 - Severe Weather (including tornadoes and winter storms) 4 - Other 5 - Heat 6 - All 7 - Multiple	Mode: No	N/A
All Greening Strategies Standardized	Greening strategies used to mitigate any hazard; potential for making links to heat mitigation (multiple mitigation strategies collapsed into two categories) 0 - None 1 - Native Vegetation/Landscape 2 - Management/Maintenance 3 - Tree/Vegetation Planting or Replacement	Mode: Green Infrastructure/Open Space	N/A

	4 - Removal/Trimming 5 - Participation in Tree City 6 - Green infrastructure/open space 7 - Multiple including green infrastructure/open space 8 - Multiple--all others		
All Energy Efficiency Strategies Standardized	Energy efficiency strategies used to mitigate any hazard; potential for making links to heat mitigation 0 - None 1 - Building Weatherization/Retrofit 2 - Other Energy 3 - Building code enforcement 4 - Green Buildings 5 - Multiple including building code 6 - Multiple other ***Note: most of the building code strategies did not state energy efficiency explicitly; however, most are the international building code which has some energy efficiency standards. As such, I decided that any building code-related implementation strategy would likely have an impact on energy.	Mode: building code	N/A
Heat Response Strategies Standardized	The non-land use mitigation strategies (referred to as "response" strategies) identified as reducing the impact of heat. 0 - None 1 - Cooling Centers 2 - Fan Distribution 3 - A/C Repair 4 - Education 5 - Networks/vulnerable population identification 6 - Implementation of Other Plans 7 - Multiple	Mode: None	N/A
County Characteristics			
Population Category	County population divided into Large, Medium, and Small categories 1 - Small: 100,000 to 249,999 2 - Medium: 250,000 to 499,999 3 - Large: 500,000 to 999,999	Median: Small Mode: Small	Min: Small Max: Large IQR: Small
County Population	County population	Mean: 332,110 Median: 252,825 Mode: N/A	Min: 105,160 Max: 998,954 IQR: 359,683 SD: 246,241

Population density	County population density per square mile	Mean: 512.23 Median: 301.2 Mode: N/A	Min: 7.2 Max: 3922.6 IQR: 458.4 SD: 743.8
County Voting 2012	How county voted in 2012 presidential election 1 - Democrat 2 - Republican	Mode: Democrat	N/A
State	Which state the county is located in	Mode: Illinois	N/A
Region	Which climatic region the county is located in	Mode: Midwest	N/A