UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

IMPORTANCE OF ENVIRONMENTAL WEATHER MONITORING FOR EMERGENCY MANAGEMENT IN OKLAHOMA

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

In partial fulfillment of the requirements for the

Degree of

DOCTOR OF PHILOSOPHY

By

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Norman, Oklahoma

2022

IMPORTANCE OF ENVIRONMENTAL WEATHER MONITORING FOR EMERGENCY MANAGEMENT IN OKLAHOMA

A DISSERTATION APPROVED FOR THE

DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL SUSTAINABILITY

BY THE COMMITTEE CONSISTING OF

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Acknowledgements

1 Chronicles 16:34*: Oh, give thanks to the LORD, for He is good; for His steadfast love endures forever!*

My people say it takes a village to raise a child. At the risk of sounding cliché, I must repeat how it took several villages to raise me and get me through my Ph.D. This journey was nothing short of a dramatic and adventurous roller coaster ride, and I am grateful for the village that held my hand, believed in me, and walked with me, especially through the dark valleys and low tides. I had the support of many people (too many to list) in the process of earning my Ph.D. in the Department of Geography and Environmental Sustainability at the University of Oklahoma.

First, I am grateful to the almighty God who in His infinite wisdom ensured that everything worked out for my good in its time. *For all things, there is a season* (Ecclesiastes 3:1-8) and so it is well with my soul.

Second, I am indebted to my committee members: Dr. Mark Shafer, for stepping in to be the chair in a time when I felt lost and confused; Dr. Chris Fiebrich, for the regular meetings and check-ins throughout the process; Dr. Aimee Franklin, for always encouraging me and believing in me; Dr. Michael Wimberly, who helped me sharpen my R skills and was always there to support me. I am grateful to Dr. Scott Greene, who provided support and encouragement through this journey, as well as Dr. Jad Ziolkowska from whom I learned a great many things. I would not have made it this far without such a great committee supporting me.

Third, I am thankful to Mr. James Hocker, who opened his doors and helped me every step of the way to attend meetings, collect data, and assist in numerous ways. Thank you to Dr. Randy Peppler and Dr. Sophie Plassin for their constant support and friendship. I acknowledge the contribution of the Faculty of the Department of Geography and Environmental Sustainability and the OU community. I have been overwhelmed by their steadfast care and concern. I am also thankful to all the wonderful people at CIWRO, the Mesonet, and OK-First, public safety officials, and the members of military installations in Oklahoma. Thank you to Dr. Laurel Smith, and Emalee Lemke. Special thanks to Dr. Claire Curry, Dr. Lixia Lambert, Tiffany Legg for always having their doors open to work with me.

Fourth, I am thankful and blessed for all the friends I made along the way. To my friends at Saint Thomas More, especially Father James Goins, Saint Joseph Catholic Church, and the OU Wesley. To Abigail, Ademidé, Aditi, Ekaterina, Fii, Filo, Dr. F. Dwomoh, Gloria A., Gloria N., Joseph, Kachi, Dr. S. Kakraba, Lené, Mahsa, Mary, Modesta, Paulina, Rafia, Rupa, Senanu, Tita, Tori, to all the folks I shared an office with and to my TAs who made my life so much easier (you have no idea exactly how much easier you made it!).

Fifth, I would like to express my profound gratitude to all my friends locally and internationally, especially back home in Ghana, who didn't let distance keep us apart. Thank you, Nana Yaa, Kobby, Vero, and Naomi. My thank yous extend to Dr. G. Lartey, Dr. R. Mahmood, Bright, Rev. Fr. Emmanuel, Rev. Sr. Anne Marie, Rev. Fr. Jude, Prof. P. Kyem, Rev. Fr. Prof. A. Afful-Broni (Ph.D.), Rev. Fr. Patrick, Rosemary, Dr. U. Kabir, Anisha, Indu, Vandalyn, Dr. V. Kuuire, and all my friends at the Holy Spirit Catholic Church in Bowling Green, Kentucky. Thank you to Nick and Diane – thank you for the walks, meals, and friendship. Thank you to Samantha and Monica for your constant support. Thank you to the extraordinary ladies of Black Girls Magic, my DND group, and the members of my Peace and Justice group.

Finally, I am also indebted to my family. Without them, I would not have made it this far. Thank you for believing in me and cheering me on. Those early morning calls forced me to start my days early and got me out of bed. Thank you to my dad Dr. Paul Yemeh, my mom Mrs. Rosina Yemeh, my sisters, Debby Yemeh and Day Pamela Yemeh, my brothers Dean Yemeh and Dr. Desmond Yemeh, and our lovely dogs, especially Shadow. Once more and through it all, they have provided the best support system I could ever hope for. Truly, I say with confidence '*Per Aspera ad Astra*'.

Notwithstanding the help and assistance I received, all mistakes in this dissertation are entirely mine.

Dolly Na-Yemeh

Funding Acknowledgements

1. Department of Geography and Environmental Sustainability.
2. Cooperative Institute for Severe and High-Impact Weather and Research Operations (CIWRO).
3. Regents Match on Adapting Socio-ecological Systems to Increased Climate Variability-Regional Ecologist and Environmental Economist-Faculty Startup [EPSCoR-2013-21], USDA-NIFA Hatch Multi-state project W4190.
4. NOAA Office of Atmospheric Research [NA16OAR4320115].
5. Graduate Student Senate Travel Awards.
6. Mesonet Student Travel Grant.

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List of Acronyms

AFB	Air Force Base
CDC	Centers for Disease Control and Prevention
DoD	Department of Defense
EM	Emergency Manager
EOC	Emergency Operation Center
FCOE	Fort Sill Fires Center of Excellence
FEMA	Federal Emergency Management Association
ITCM	Individual Travel Cost Methos
MAR	Modernization and associated restructuring
MCAAP	McAlester Army Ammunition Plant
NCEI	National Centers for Environmental Information
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
OK Mesonet	Oklahoma Mesonet
OK-First	Oklahoma's First-response Information Resource System using Telecommunications
PANYNJ	Port Authority of New York & New Jersey
PSO	Public Safety Officials
SCIPP	Southern Climate Impacts Planning Program
SERDP	Strategic Environmental Research and Development Program
TCM	Travel Cost Method
ZTCM	Zonal Travel Cost Method

Chapter 1: Introduction

1.1 Background and introduction

Extreme and hazardous weather events impact diverse communities and sectors of the economy. Mitigating the impacts of these events is an ongoing challenge. Educating and training decision-makers on how to prepare and respond to weather disasters has shown to be effective in mitigating impacts, but objective assessments are still relatively new.

Between 1953 and March 2022, Oklahoma was ranked second in disaster declarations for severe storms and severe ice storms (FEMA 2022). Oklahoma also has the fourth-highest number of disaster declarations (FEMA 2022). Oklahoma is prone to extreme weather events like storms, tornadoes, hail, winds, and floods. Oklahoma is also a high-risk area for violent tornadoes in the United States (Hatzis et al. 2019). Undeniably, not only are severe weather events disruptive to the local communities and economies, but they are also expensive. Extreme events can cause loss of lives and property worth billions of U.S. dollars annually (NCEI 2022a; Smith 2020, 2019). Oklahoma serves as a unique testbed to research weather data sources, the value of decisions, and the impact of extreme events.

One such sector affected by hazardous weather events in Oklahoma is military installations. Oklahoma is home to five federal installations (Altus Air Force Base (AFB), Fort Sill Fires Center of Excellence, McAlester Army Ammunition Plant, Tinker AFB, and Vance AFB). These installations are not only vital to the preparedness and the security of the United States, but they are also economic engines for the State (Boone et al. 2019; Chiappe 2011). Brown et al. (2002) argued that effective preparedness, integrated warning systems, medical response, and new technology were necessary to prevent death and injuries in the likelihood of hazardous weather events. Emergency managers and public safety officials are responsible for tasks to help avoid and respond to natural and human-caused hazards (Lindsay 2012). Therefore, emergency managers integrate a variety of data sources and rely heavily on forecasts to accomplish the goals of their profession to save lives and property by planning for and anticipating the unexpected (Morss et al. 2008; Morss and Ralph 2007; Stewart et al. 2003). Emergency managers usually serve as the link between the public and NWS forecasters. Thus, emergency managers rely on NWS forecasters, broadcasters, and other resources to make judgment calls to save lives and property.

With the growth in automated weather networks and increased data applications (Fiebrich 2009), there has been a proliferation of weather information available through various sources to emergency managers in recent times. The common theme of this dissertation research is how weather and climate impact emergency management, both from a decision-making perspective and an economics perspective. This research aims to understand the relevance of environmental weather monitoring for decision-making in Oklahoma. The dissertation is split into two main parts. Part one focuses on public safety officials who rely on the OK-First (Oklahoma's First-response Information Resource System using Telecommunications) program for decision-making and the resulting economic value of such weather support systems. Part two focuses on the impacts of extreme weather events on an individual sector, using military installations as a case study.

Chapters two and three focus on the OK-First program. OK-First is an outreach program of the Oklahoma Mesonet, built upon successes in implementing the Oklahoma Mesonet (Brock et al. 1995). The OK-First program has provided training, follow-up support, networking opportunities, weather education, and access to critical real-time weather data to over 1800+ public safety officials (Hocker et al. 2018). Recent testimonials from OK-First users emphasized the value of providing non-scientific audiences with complex meteorological information coupled with well-designed, relevant, and routine training (Hocker et al. 2018). Through the program, local officials have been empowered to make decisions such as closing bridges during floods and improving evacuations during severe weather (Morris et al. 2002). As a result of the OK-First program's long-standing history of supporting public safety officials, the OK-First program provided a good case study to examine the benefits of a system for public safety and emergency management and assess the value of weather decision support systems. Oklahomans have made great strides in local responses to weather-impacted emergencies using the OK-First (Johnson et al. 2015; Gruntfest and Handmer 1999; Morris et al. 2002, 2001).

Additionally, emergency managers' testimonials over the past two decades suggest that the OK-First has become an integral part of emergency management decision-making in Oklahoma. As a result, the emergency management profession in the State has evolved, equipping emergency managers with the skills, knowledge, and expertise to deal with severe weather. Chapter two details the impacts of the OK-First program, and chapter three examines the economic value of the program for public safety officials.

Chapter four delves into decision-making and impacts of weather events on military installations. These installations are not only vital to the preparedness and the security of the United States, but they are also economic engines for the State (Boone et al. 2019; Chiappe 2011). However, extreme weather events such as floods, fires, and extreme temperatures affect the day-to-day operations of these installations (Garfin et al. 2021, 2017; Smith et al. 2010). Chapter four thus examines the impacts of extreme weather on two of these installations.

The importance of public safety officials during hazardous weather conditions cannot be overemphasized. Weather decision support systems are an example of programs available to public safety officials to help them accomplish their goal of protecting lives and property. However, little is known about user interactions with tools, decisions made, estimated savings made, and the value of using weather decision support systems for public safety. Chapters two and three fill a gap in the literature by assessing the perceptions, beneficiaries, applications, and value of weather decision support systems.

Additionally, extreme weather conditions affect different sectors of the economy, particularly the defense sector across the United States. This work delves into the defense sector in Oklahoma to examine the impacts of extreme weather on military installations. This research fills the gap in identifying the significance of weather monitoring to military installations and the effects of extreme events. These studies emphasize the relevance of environmental weather monitoring, particularly in storm-prone areas. The results stress the need for investments in resources and collaboration with multiple stakeholders to mitigate, prepare for, respond to, and recover from hazardous weather events.

Together, these chapters detail:

i. what motivates emergency managers to seek training and information sources related to weather events
ii. how important (in value and impact) is the training and data to emergency managers
iii. how do sources and constraints differ between those in the military and those in local government positions

There is a growing interest in the value of weather data, dissemination of information, and the need to find ways to protect lives and property from extreme weather events. Disasters transcend local and international boundaries. As such, results across the three chapters can be adopted on various scales for decision making and support. Overall, these chapters help improve decision-making processes to guide weather-related design and the development of future emergency management programs. The chapters further draw light to the impacts of hazardous weather events in various sectors of the economy.

1.2 Dissertation overview

The dissertation is organized into five chapters. This chapter introduces the research questions and provides an overview of the work. Chapters 2, 3, and 4 are standalone papers. Chapter 5 summarizes and provides conclusions for the three studies.

Chapter 2: Assessing the impacts of a weather decision support system for Oklahoma Public Safety Officials (Accepted for publication in Weather, Climate and Society)

Chapter 3: Economic value of a weather decision support system for Oklahoma Public Safety Officials (Submitted for publication)

Chapter 4: The impacts of extreme weather on military installations (In preparation).

1.3 References

Boone, M., L. Kos, and M. A. Shafer, 2019: Weather and Climate Impacts on Military Operations Workshop Summary. 20 pp. http://www.southernclimate.org/documents/MilitaryOperationsWorkshop.pdf.

Brock, F. V., K. C. Crawford, R. L. Elliott, G. W. Cuperus, S. J. Stadler, H. L. Johnson, and M. D. Eilts, 1995: The Oklahoma Mesonet: A Technical Overview. J. Atmos. Ocean. Technol., 12, 5–19, https://doi.org/10.1175/1520-0426(1995)012<0005:TOMATO>2.0.CO;2.

Brown, S., P. Archer, E. Kruger, and S. Mallonee, 2002: Tornado-related deaths and injuries in Oklahoma due to the 3 May 1999 tornadoes. Weather Forecast., 17, 343–353, https://doi.org/http://dx.doi.org/10.1175/1520-0434(2002)017<0343:TRDAII>2.0.CO;2.

Chiappe, J., 2011: Oklahoma's Five Military Installations: An Economic Impact Report. 30 pp.

FEMA, 2022: Disaster Declarations by State/Tribal Government. Fed. Emerg. Manag. Assoc.,. https://www.fema.gov/disasters/state-tribal-government/ (Accessed March 8, 2022).

Fiebrich, C. A., 2009: History of surface weather observations in the United States. Earth-Science Rev., 93, 77–84, https://doi.org/10.1016/j.earscirev.2009.01.001.

Garfin, G., and Coauthors, 2021: A new mission: Mainstreaming climate adaptation in the US Department of Defense. Clim. Serv., 22, 100230, https://doi.org/10.1016/J.CLISER.2021.100230.

Garfin, G. M., and Coauthors, 2017: Assessing Climate Change Risks : Lessons learned from DoD installations in the Southwestern United States. 82 pp.

Gruntfest, E., and J. Handmer, 1999: Coping with flash floods. 1st ed. Springer Science, 322 pp.

Hatzis, J. J., J. Koch, and H. E. Brooks, 2019: Spatiotemporal Analysis of Near-Miss Violent Tornadoes in the United States. Weather. Clim. Soc., 11, 159–182, https://doi.org/10.1175/WCAS-D-18-0046.1.

Hocker, J. E., A. D. Melvin, K. A. Kloesel, C. A. Fiebrich, R. W. Hill, R. D. Smith, and S. F. Piltz, 2018: The evolution and impact of a meteorological outreach program for public safety officials : An update on the Oklahoma mesonet's ok-first program. Bull. Am. Meteorol. Soc., 99, 2009–2024, https://doi.org/10.1175/BAMS-D-17-0100.1.

Johnson, V., R. Jeffries, G. Byrd, W. Schreiber-Abshire, E. Page, B. Muller, and T. Alberta, 2015: Celebrating comet's 25 years of providing innovative education and training. Bull. Am. Meteorol. Soc., 96, 2183–2194, https://doi.org/10.1175/BAMS-D-14-00276.1.

Lindsay, B. R., 2012: Federal emergency management: A brief introduction.

Morris, D. A., K. C. Crawford, K. A. Kloesel, and J. M. Wolfinbarger, 2001: OK-FIRST: A meteorological information system for public safety. Bull. Am. Meteorol. Soc., 82, 1911–1923, https://doi.org/10.1175/1520-0477(2001)082<1911:OFAMIS>2.3.CO;2.

——, ——, ——, and G. Kitch, 2002: OK-FIRST: An example of successful collaboration between the meteorological and emergency response communities on 3 May 1999. Weather Forecast., 17, 567–576, https://doi.org/10.1175/1520-0434(2002)017<0567:OFAEOS>2.0.CO;2.

Morss, R. E., and F. M. Ralph, 2007: Use of Information by National Weather Service Forecasters and Emergency Managers during CALJET and PACJET-2001. Weather Forecast., 22, 539–555, https://doi.org/10.1175/WAF1001.1.

——, J. K. Lazo, B. G. Brown, H. E. Brooks, P. T. Ganderton, and B. N. Mills, 2008: Societal and economic research and applications for weather applications for weather forecasts. Am. Meteological Soc., 335–346, https://doi.org/10.1175/BAMS-89-3-335.

NCEI, 2022: U.S. Billion-dollar Weather and Climate Disasters, 1980 - present. Natl. Centers Environ. Inf., https://doi.org/10.25921/STKW-7W73.

Smith, A. B., 2019: 2018's Billion Dollar Disasters in Context. Climate.gov,. https://www.climate.gov/news-features/blogs/beyond-data/2018s-billion-dollar-disasters-context (Accessed June 10, 2020).

——, 2020: 2010-2019: A landmark decade of U.S. billion-dollar weather and climate disasters. Climate.gov,. https://www.climate.gov/news-features/blogs/beyond-data/2010-2019-landmark-decade-us-billion-dollar-weather-and-climate (Accessed June 10, 2020).

Smith, W., D. Schultz, D. Whitford, J. Barry, D. Uyesugi, W. Mitchell, and B. Stamey, 2010: Climate Change Planning for Military Installations. http://www.mwcog.org/uploads/committee-documents/ll1dXltf20120515090746.pdf.

Stewart, T. R., R. A. Pielke, and R. Nath, 2003: Understanding user decision making and the value of improved precipitation forecasts. Am. Meteological Soc., 223–236, https://doi.org/10.1175/BAMS-85-2-223 In.

Chapter 2: Assessing the Impacts of a Weather Decision Support System for Oklahoma Public Safety Officials[1]

Abstract

Oklahoma's First-response Information Resource System using Telecommunications (OK-First) has been used for the past 25 years to provide education, training, connections, and follow-up support for public safety officials with emergency management responsibilities in Oklahoma. Public safety officials use OK-First training and Oklahoma Mesonet tools to plan and make decisions to save lives and property. However, little is known about user interactions with tools, decisions made, and estimated savings using a weather decision support system. This study used a mixed approach to collect and analyze data from three key sources to assess the perceptions, beneficiaries, and applications of weather support systems for public safety officials. Results showed that a diverse set of tools were needed and used by public safety officials to make decisions in hazardous weather conditions. OK-First tools resulted in estimated self-reported cost savings of over $1.2 M for 12 months. This study provides a crucial step in determining user interactions with tools, training, and services to better understand weather decision support systems used during hazardous weather.

Keywords: Cost Savings, Emergency Management, Google Analytics, OK-First, Oklahoma Mesonet, Public Safety Officials, Weather Decision Support Systems

[1] The majority of this chapter appears in a published article with the same title in *Weather, Climate and Society*.

2.1 Introduction and motivation

Emergency management primarily consists of the four main components of the comprehensive emergency model introduced in the mid-1970s (Gruntfest 1998; Waugh 1994). The model divides emergency management functions into mitigation, preparedness, response, and recovery (Weaver et al. 2014; Waugh 1994; McLoughlin 1985; Petak 1985). These four elements include a significant part of the existing philosophical vocabulary in emergency management and are widely recognized as the starting point for policy and program design administration (Waugh 1994; Petak 1985). Emergency management remains an essential component in most economies, as both natural and human-made disasters cannot be prevented.

Public safety officials with emergency management responsibilities have the vital task of alerting the public of impending inclement weather by being liaisons between local National Weather Service (NWS) forecasters and the public. *Public safety official* is a broad term that for the purposes of this study refers to the variety of decision makers that make weather-related decisions to protect specific groups of people. These decision makers include, but are not limited to, emergency managers, law enforcement officials, fire officials, school officials, health officials, and city/county/state/tribal government officials. While public safety officials are the focus of this paper, the term Emergency Manager (EM) will be used predominantly in discussing relevant literature due to much of the previous research on weather decision makers being focused specifically on EMs.

EMs make time-sensitive decisions to warn the public of threats and link the NWS and other stakeholders (Baumgart et al. 2008). Additionally, EMs direct and protect mobile storm spotters responsible for providing "ground truth" data to better assess weather hazards (Baumgart and Bass 2006; Baumgart et al. 2006). Thus, the role of EMs cannot be overemphasized, particularly in parts of the country prone to hazardous weather events, such as the Southern Great Plains.

Not only does the NWS work with EMs to ensure their target audience receives their message, but they rely on EMs to ensure their audience understands, believes, and responds appropriately to their message (Weaver et al. 2014). Weaver et al. (2014) also argued that this connection is critical because local EMs are responsible for identifying risks and managing vulnerabilities within a community. EMs must carry out these tasks in a way that promotes coordination, flexibility, and professionalism. Thus, one can infer that many economies risk losing lives and property if this link is broken.

As early as 1985, researchers have studied the impact of emergency response on life and property saved (Petak 1985). However, these decision makers have been a challenging group to study because of a vast diversity in job roles, responsibilities, jurisdiction, training, tools available, responsibilities, experience level, and decision-making methods (Baumgart et al. 2008; Baumgart and Bass 2006; Baumgart et al. 2006; Doswell et al. 1999; Lusk et al. 1990).

Perhaps the greatest challenge for officials responsible for public safety is integrating information from multiple sources with different content, structure, and update rates (Baumgart and Bass 2006). According to Morss and Ralph (2007), EMs have to follow a general decision cycle involving the identification of an event's increasing potential of occurrence. This is usually accomplished by deciding whether an event is likely or imminent, choosing to activate or deactivate their Emergency Operation Center (EOC), and completing after-action reports to document what happened. It is essential to recognize that EMs have reported that 78% of all disasters that had taken place were weather-related, yet, EMs are usually not meteorologists (Weaver et al. 2014). Additionally, the authors reported that only 31% of training classes EMs attended were weather-related classes. While training on a diverse set of disasters is important (e.g., terrorism, industrial or hazardous chemical incidents, transportation, and construction projects), one might wonder if the training on integrating weather information into decision-making is adequate.

The NWS has undergone many transformations, including the most recent "modernization and associated restructuring" (MAR) (Friday 1994). The MAR fundamentally changed the NWS field office structure to ensure that rapid detection, timely forecasts, and warnings are delivered to the public while providing greater interaction with local communities (Friday 1994). These transformations have helped to connect NWS information to emergency managers and ensure the integration of weather information to decision making (Uccellini and Ten Hoeve 2019). Many NWS offices hold integrated warning team meetings to improve communication, understanding, and relationships between EMs and NWS.

While there is a proliferation of weather data and resources freely available, Hocker et al. (2018) argue that officials should never be expected to make well-informed decisions from weather data without appropriate training. Addressing how EMs could overcome this challenge, Baumgart and Bass (2006) stressed the need to use tools that present weather information in multiple formats and with different update rates in simulated real-time to help EMs make informed decisions.

There has always been a myriad of resources for EMs to use (Morss and Ralph 2007; Morris et al. 2002), although there is often a disconnect with dissemination, response, and planning (Hoss and Fischbeck 2016; Weaver et al. 2014; Morris et al. 2002, 2001). In effect, not only is there a need to improve EMs' training and decision support tools, but an in-depth investigation is necessary to understand the needs and cues EMs require to make assessments and decisions during severe events (Hocker et al. 2018; Baumgart et al. 2008). Additionally, Baumgart et al. (2006)

developed a descriptive decision-making model of weather information usage, weather assessments, and decisions made during severe weather to help EMs plan for events. The authors believed that tools and models helped develop better decision support systems, improved training, and provided insight on how innovative weather information could affect the role of emergency managers in protecting the public.

The Oklahoma Mesonet has served as a model network for the establishment of statewide monitoring networks across the United States and abroad because of its accuracy, consistency, validation, broad scope, range of variables collected, monitoring and analysis, and maintenance of near-complete records (Ziolkowska et al. 2017; McPherson et al. 2007; Fiebrich et al. 2006; Shafer et al. 2000). As an outreach program of the Oklahoma Mesonet, the OK-First program was introduced in the mid-1990s to fill a service void in Oklahoma's weather warning system by bridging the gap between the NWS and public safety officials, especially in rural Oklahoma (Morris et al. 2002, 2001). While other weather-related training programs existed at that time (e.g., National Weather Service Spotter Training, Cooperative Program for Operational Meteorology, Education, and Training, etc.), none addressed a critical unmet need of decision makers in Oklahoma – the need for real-time weather and radar data as well as training for proper interpretation of that information. The OK-First program was the response to those needs and paired training with data from the newly commissioned Oklahoma Mesonet. The program was created to provide routine weather and radar training from degreed meteorologists, access to critical real-time weather data, follow-up support, and networking opportunities. Now nearly 25 years later, OK-First has grown to more than 800 active members and continues to provide training and password-protected data access to its members.

Morris et al. (2002) reported that the OK-First program had become a catalyst for change in many local governments. Because of high-quality weather data tools, regular training classes, and continual follow-up support, local officials are increasingly empowered to make impacts such as closing bridges during floods, saving property in wildfires, improving evacuations after hazardous spills, and protecting audiences at outdoor events (Morris et al. 2002). Participation in the OK-First program is competitive, restricted to non-profit officials with public safety responsibilities, and dependent on successful completion of a four-day OK-First Certification class. Additionally, once a member is certified in the OK-First program, they are required to attend re-certification classes no less than once every 18 months. The OK-First program has shown immense value in providing non-scientific audiences with complex meteorological information when paired with well-designed, relevant, and routine training (Hocker et al. 2018; Morris et al. 2002).

The literature suggests a need to synthesize and provide weather information and training to EMs who can then apply the training to make informed decisions; however, this work has not been sustained or rarely present at the state level in other regions. Other programs, such as NC-First in North Carolina, have been successful; however, they were discontinued due to a lack of funding. While efforts to train decision makers on weather topics have grown in recent years via Federal Emergency Management Association (FEMA) certified classes offered by the National Disaster Preparedness Training Center, continual weather training is still vitally needed at the local level. Information collected from participants of the OK-First program offers a unique opportunity to analyze the impacts of an over 20-year sustained program.

Whereas other scientists have focused on using surveys and interviews to assess this unique public safety community (e.g., Hoss and Fischbeck 2016; Weaver et al. 2014; Baumgart et al.

2008; Morris et al. 2002; 2001; James et al. 2000), this research more broadly assesses impacts through three separate instruments: surveys, Google Analytics, and NOAA's Storm Events Database. This chapter fills a gap in the literature to assess the perceptions, beneficiaries, and applications of weather support systems for decision-making for public safety officials. This research also reveals specific decisions public safety officials made and an estimate of potential savings. In an effort to assess the true impact of a weather decision support system, this study seeks to answer the following research questions:

1. What products and tools are most important to OK-First users to allow them to accomplish their roles in their various jurisdictions?
2. How frequently do public safety officials report using OK-First tools?
3. Are there geographic variations in OK-First tool use?
4. What are the key decisions public safety officials make to save lives and property, and how often are they made?
5. How can the self-reported economic impact of a decision support system be quantified?

2.2 Data and methods

This study used a mixed approach of instruments and methods to collect and analyze data from three key sources: a) survey data, b) Google Analytics data, and c) NOAA's Storm Events Database. The choice to use a mixed approach grew from informal meetings with participants during OK-First classes and emergency management conferences, meetings with stakeholders, and email and phone conversations with managers of different state Mesonet systems across the country.

2.2.1 *Survey design and population*

A survey was developed through feedback and meetings with numerous public safety officials and stakeholders across Oklahoma. The participant survey was designed to gather as much data as possible without being too much of a time burden for the participants. The total number of questions was 24 and the maximum number of questions answered with logic branches was 18. The survey consisted of closed and open-ended questions. Participants responded to questions on OK-First engagement, decisions made using OK-First, and other resources used.

1) IMPLEMENTATION

The survey was distributed following Institutional Review Board approval (#11814). The anonymous survey link was shared with all 812 active OK-First members. Between 3 April 2020 and 11 May 2020, 280 respondents completed the survey, which yielded a 34% response rate.

2) BACKGROUND OF MEMBERS

Before focusing on several of the key questions posed in the survey, it is important to briefly gain an understanding of the background of the survey respondents. Of the 280 respondents, 59% had participated in the OK-First program for one to five years, 23% had been in the program for six to ten years, and 18% had been in the program for more than ten years. Regarding the number of OK-First classes attended by the respondents, approximately 67% had attended one to five OK-First classes, 22% had attended six to ten classes, and 11% had attended more than ten classes. The geographic distribution of respondents covered all 9 Oklahoma climate divisions (Figure 2-1), with the greatest share (39%) coming from central Oklahoma. Central Oklahoma is the most populous part of the state and has the greatest concentration of public safety agencies (including local, county, and state agencies).

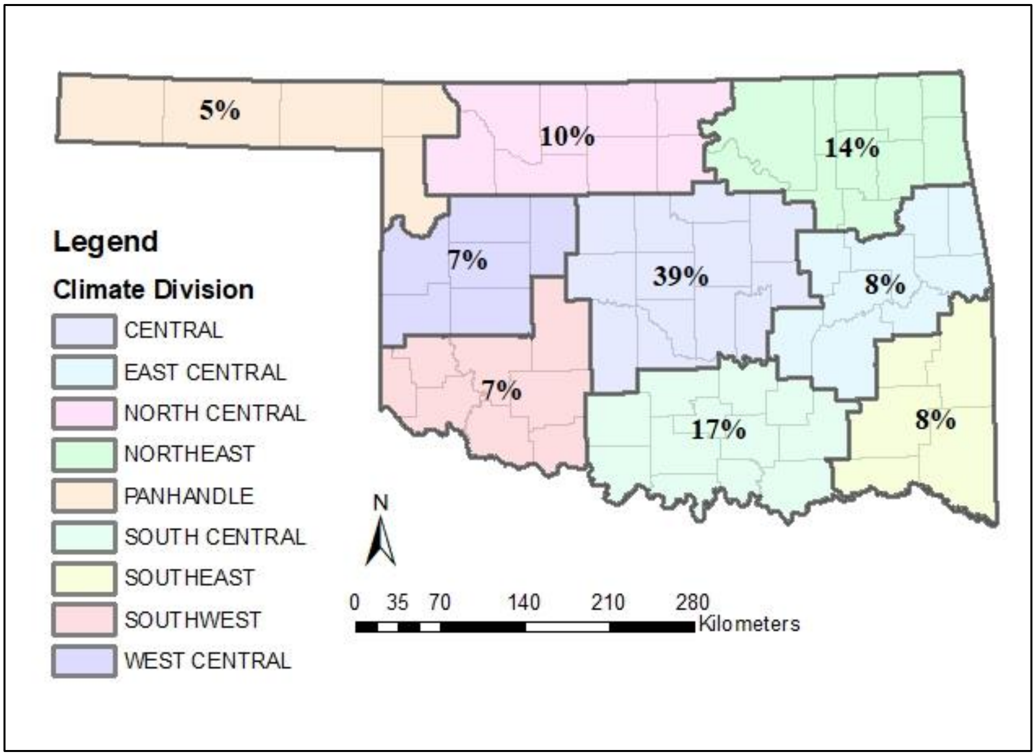

Figure 2-1: Geographic distribution of survey respondents by climate division

Table 2-1 depicts the job type each survey participant identified. Nearly 80% of the respondents selected either emergency manager, fire official, or law enforcement. A few write-in job types for the "other" category included storm spotter, public health official, engineer, jail administrator, and amateur radio operator.

Table 2-1: Job types of OK-First Survey participants (N = 280)

Job Type	**Percentage**
Emergency manager	43%
Fire official	19%
Law enforcement	17%
911/Dispatcher	10%
Emergency medical responder	10%
Other	8%
City official	6%
Non-profit Voluntary Organization Active in Disaster	5%
School official	4%
Tribal official	3%
County official	2%
State official	2%
Health official	1%

2.2.2 *NOAA's Storm Events Database*

The storm events database archive is maintained by NOAA at https://www.ncdc.noaa.gov/stormevents/ftp.jsp and contains data from January 1950 to October 2020 (at the conclusion of the analysis). The database documents:

a. events whose measured intensity exceeded criteria for severe storms (i.e., winds $\geq$ 58 mph, hail $\geq$ 1-inch diameter, or a tornado);

b. the occurrence of storms and other significant weather phenomena having enough intensity to cause loss of life, injuries, significant property damage, and disruption to commerce;

c. rare, unusual weather phenomena that generate media attention, such as snow flurries in South Florida; and

d. other significant meteorological events, such as record maximum or minimum temperatures or precipitation that occur in connection with another event (https://www.ncdc.noaa.gov/stormevents/).

Reports included in the NOAA storm database are each vetted by location, and only officially sanctioned terms are used. This ensures a comprehensive dataset for recorded and reported events across the nation. The exploration of the storm events database provided key details of storms in Oklahoma and when they occurred. The storm events were then compared with the OK-First website statistics to understand the resources public safety officials used to make decisions in Oklahoma.

2.2.3 *Google Analytics data*

Google Analytics (https://analytics.google.com) is a platform that collects data and compiles it into a variety of reports on user interactions. Different organizations use web analytics to understand the interaction between a web page and visitors to the web page (Phippen et al. 2004). Web analytics involves collecting, monitoring, measuring, analyzing, and reporting web usage data to meet organizations' goals and users' expectations (Hasan et al. 2005). Web analytics data are collected by Google and can be compared over time (Kent et al. 2011). The OK-First program provides a decision support web page for situational awareness during hazardous weather events and human-made disasters. The OK-First program is currently on its 4th generation decision-support web page, hereafter referred to as the OK-First Weather Briefing page. The page was launched in 2016. Kent et al. (2011) argued that three to six months is long enough for most organizations with a well-established web presence to see meaningful data in its Google Analytics statistics. The results presented here utilized five years of analytics (2016 – 2020) to provide a robust period from which to understand frequency of use of the OK-First Weather Briefing page, especially during hazardous weather events.

In Google Analytics terminology, a *session* refers to a group of web hits recorded for a user in each period. *Hits* are defined as user interactions with the OK-First Weather Briefing page. A user can generate one or more sessions in Google Analytics. Generally, the number of users and sessions follow the same trend. These data help to identify both when and how many users interacted with the OK-First Weather Briefing page. The Google Analytics data was compared with storm events reported and survey results of how participants use data from the OK-First program.

2.3 Results

2.3.1 *Assessment of perceptions*

Members of the OK-First program include a diverse group comprised of more than ten different job types (Table 2-1). Over 75% of participants considered the training, technology, follow-up support, and OK-First connections as very important for their duties within their various jurisdictions (Figure 2-2). Ninety percent of participants also highlighted other specific services provided by the OK-First program as being very important to accomplish their work duties. Respondents specified these other services as refresher training, continual updates, radar knowledge, latest data, and safety of first responders at incidents (not shown).

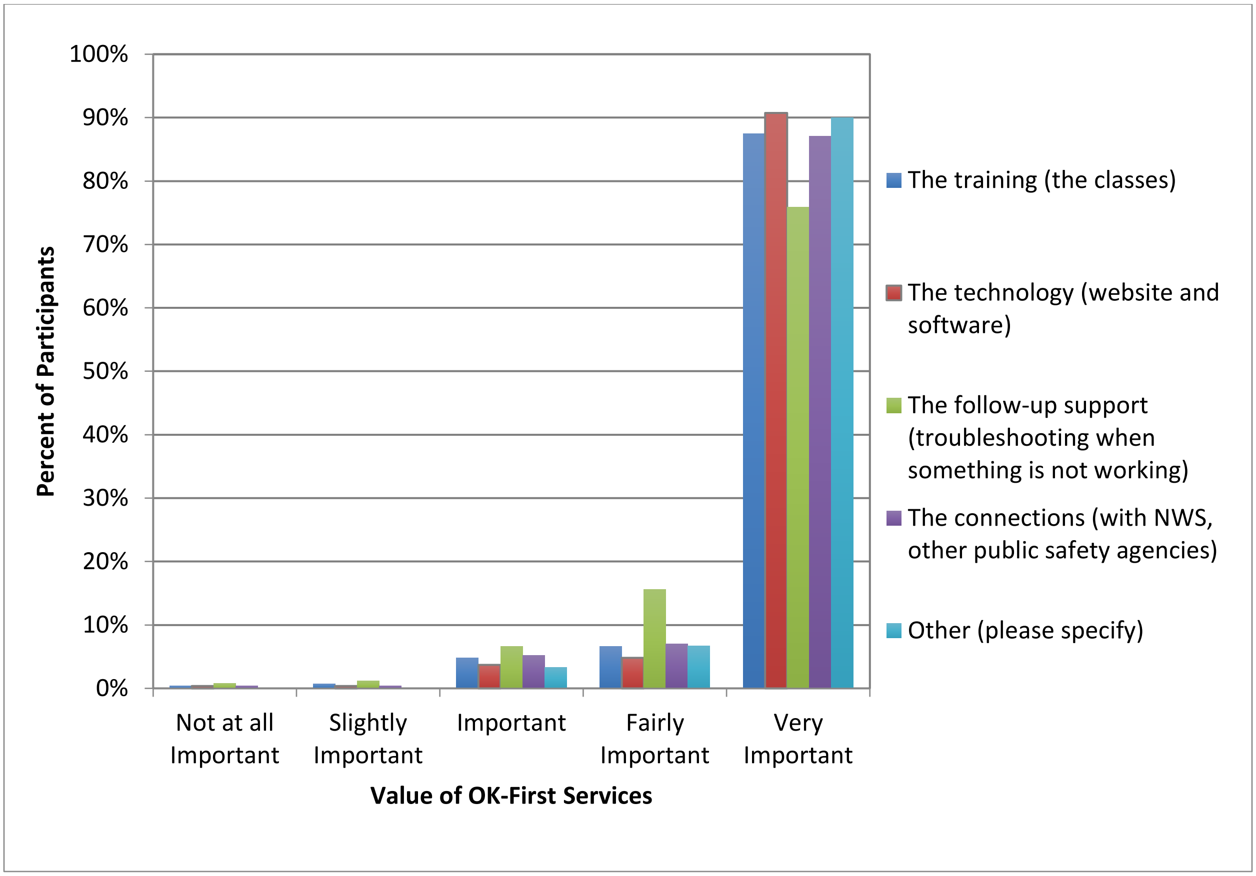

Figure 2-2: Responses to the survey question "In terms of importance to your work duties, how do you value the services you receive from OK-First?" (Note: respondents could only select one response for each category)

The OK-First program provides a variety of tools to users, including an iPhone and Andriod App (hereafter referred to as the Mesonet app), a publicly available webpage (https://www.mesonet.org), the Weather Briefing page, and a stand-alone radar viewer for Windows computers called RadarFirst. Figure 2-3 summarizes the frequency of use for each tool. The Mesonet app, Mesonet webpage, and OK-First Weather Briefing Page are used most commonly on a daily basis. Of note, more than 50% of the respondents indicated that they use the Mesonet app every day.

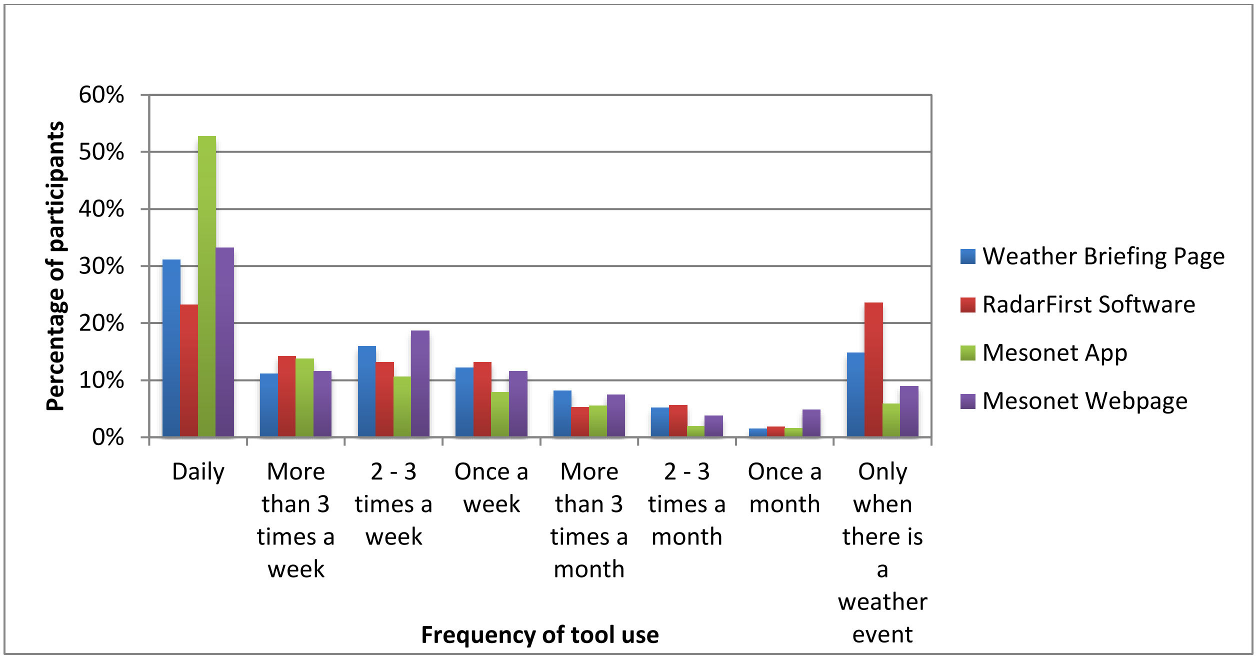

Figure 2-3: Frequency of use of OK-First tools

Regional differences exist in the most commonly used OK-First tools particularly on a daily basis and during weather events. Those results are shown in Figure 2-4, reinforcing that no single tool can fulfill the weather information needs for a diverse community of public safety officials. Figure 2-4a shows that the top two most used tools on a daily basis included the Mesonet app and the Mesonet webpage. This result suggests that OK-First users across most areas need basic weather information each day, which can be satisfied through the app and the publicly available Mesonet webpage. However, when there is a weather event, tool use by OK-First users changes significantly (Figure 2-4b). Respondents statewide consistently reported that their most frequently used tool was either the RadarFirst software or the OK-First Weather Briefing page on a weather event day. Both of these tools are password-protected and only available to OK-First users who are up-to-date on their training requirements. These two tools provide interactive radar products (i.e., the RadarFirst software) and a customizable multi-panel webpage that can display a variety of products that a user chooses, such as interactive radar data, Mesonet maps, NWS warnings, satellite data, and more (i.e., the OK-First Weather Briefing page). With a higher level of customization and interactivity, these tools better support (as compared to the static tools) critical decision-making during short-fused situations. Given the usage of different tools on varying timescales (e.g., daily versus during weather events), these results illustrate that public safety officials cannot rely on a single one-size-fits-all weather tool but require a portfolio of tools to remain weather aware.

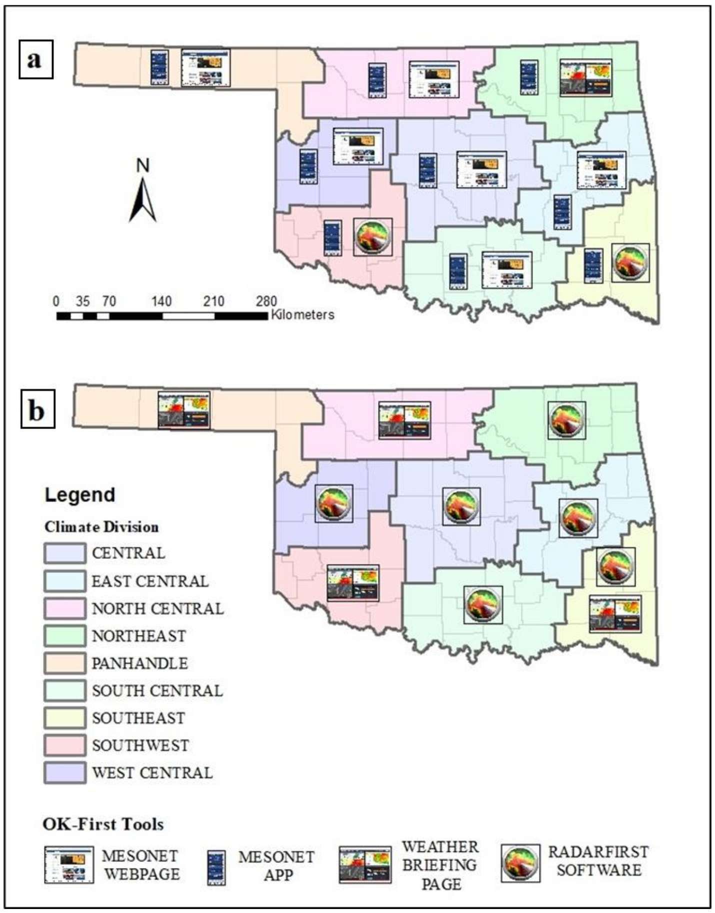

Figure 2-4: Geographic variations of a) the top two most-used OK-First tools on a daily basis and b) the most used tool during a weather event

2.3.2 *Assessment of beneficiaries (Public safety officials and communities)*

As discussed in the previous sections, the OK-First program provides training, technology, follow-up support, and connections to the program's participants. The users can then use OK-First tools and information to make decisions for their various jurisdictions (Figure 2-5). These decisions generally depended on the time of year and the specific role of a public safety official in their jurisdiction. Over 60% of participants recalled making decisions on floods, winter weather, and severe storms one to five times within a 12-month period. For respondents who reported making weather-related decisions six to ten times in the previous 12 months, the most common cause was for severe thunderstorms (26%), closely followed by winter weather (21%). For those respondents who reported making decisions more than ten times, severe weather, fire weather, and others were noted by more than 25% of respondents. After verifying the assumptions of a Chi-square independence test (i.e., random sample, independence, mutually exclusive groups), the Chi-square independence test showed a significant association between the frequency and type of weather-related decisions (χ^2 = 39.188, df = 8, $\rho<0.001$).

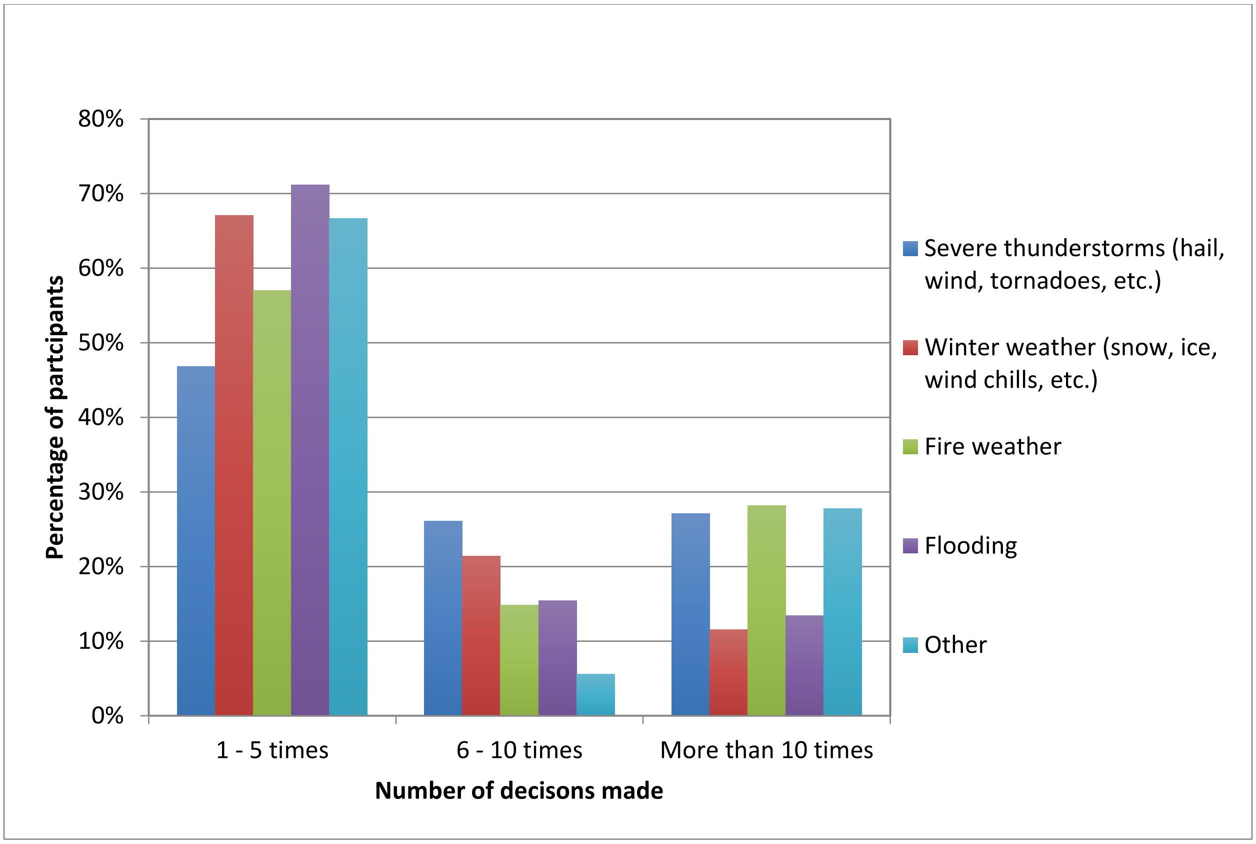

Figure 2-5: Number of times OK-First tools and information was used to make decisions over a 12-month period (Note: respondents could only select one frequency category for each weather event type)

When surveyed on the specific decisions that were made (Figure 2-6), over 54% of respondents used their OK-First training to inform an official (e.g., mayor, superintendent, county commissioner, etc.) so that they could make community decisions based on an impending weather event. Forty-nine percent (49%) pre-positioned resources for an imminent weather event. Forty-four percent (44%) initiated or provided a "significant weather potential" update/notice to public officials, the general public, etc. Thirty-eight percent (38%) reported that they sounded an outdoor warning system for their community. Thirty-three percent (33%) helped make a closure or delayed opening decision (school, government offices, etc.), while 32% generated an adequate response after an impactful weather event. Between 8% and 24% canceled or postponed a minor community event (e.g., parade, group meeting), included an OK-First trained staff member in the Emergency Operations Center to provide weather support during an event (scheduled or emergency), canceled or postponed a major community event (e.g., outdoor concert or sporting event), closed a road or re-routed traffic for an impending flooding event or other significant weather factors (e.g., re-routing first responders due to active tornado path of travel), assisted with a law enforcement investigation, or helped with a construction project (e.g., road, building, etc.). While these decisions made could be categorized as either mitigation, preparedness, response, or recovery (e.g., the four main components of the comprehensive emergency management model) most responses fit within the categories of response and recovery (Figure 2-6 and Appendix C).

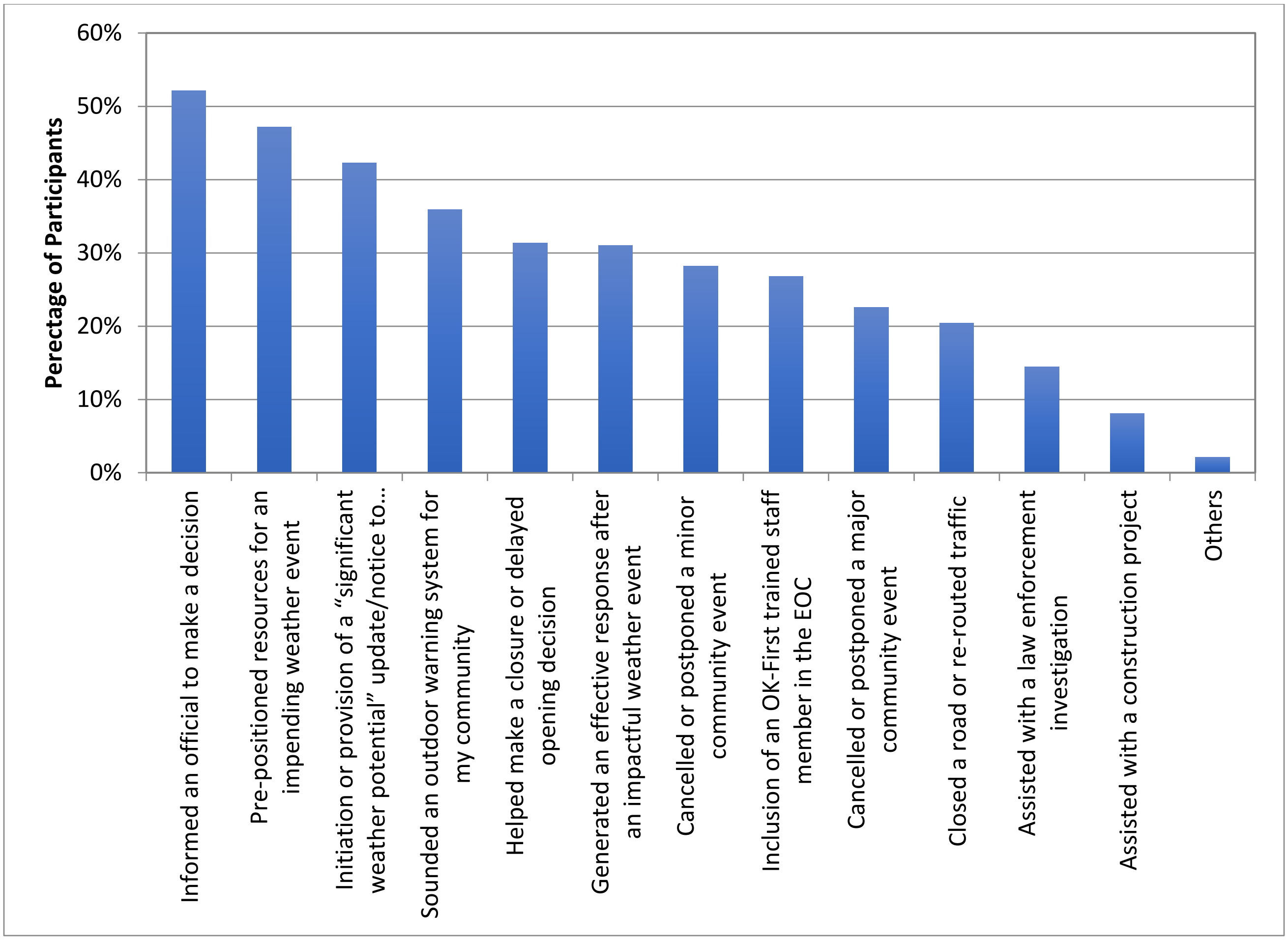

Figure 2-6: Decisions made using OK-First tools and information

There was also a statistically significant relationship between the number of years respondents participated in the program ($p<0.001$), the number of classes participants attended ($p = 0.026$), and their ability to make decisions for their jurisdiction. The survey results show that most OK-First participants use the tools regularly and make decisions frequently. While it is possible that this connection can be attributed to the fact that those public safety officials with the time and interest to devote to their jobs take additional classes and thereby make better decisions, survey results indicate that the more classes users took, the more likely they were to make weather-related decisions for their jurisdiction. Additionally, survey results revealed that the more recently a respondent took an OK-First training class, the more likely they were to make a weather-related decision.

Approximately 42% of respondents who made decisions over the previous 12 months were able to estimate how much the OK-First program saved their jurisdiction. Fifty percent (50%) indicated that the OK-First program saved their community over $10,000 over the past 12 months, 35% reported savings of $1,000 - $10,000, and 15% saved under $1,000. These respondents also provided specific examples of events that supported their estimates (see appendix). Participants who found it challenging to estimate costs also provided explanations including not knowing how to estimate the cost of losing a life and the difficulty in calculating "damage avoided" cost.

2.3.2 *Assessment of applications*

1) GOOGLE ANALYTICS

a. Trends in the diurnal use of tools

By analyzing Google Analytics data from 2016 – 2020 for the OK-First Weather Briefing page, it was possible to explore the behavior of OK-First members and how they accessed the tool. In general, the period of greatest website usage mirrored the traditional workday hours of 7 am – 4 pm (LT) as shown in Figure 2-7a, with the heaviest usage during the 7 – 10 am (LT) timeframe (accounting for 36% of their time on the page). A secondary maximum in website usage was also observed in the 1 – 3 pm (LT) timeframe. Website usage declined in the evening, though it reached a relative maximum around 8 pm before declining significantly during the overnight hours. These data suggest that users typically check weather data early in their workdays to plan for the day, followed by continued monitoring of information in the afternoon before tapering off late in the day into the overnight hours. Because Google Analytics resets all sessions at midnight, this likely accounts for the slight increase in sessions at the midnight hour.

b. Trends in the weekday and weekend use of the tools

Google Analytics data show that OK-First participants use the Weather Briefing page considerably more on weekdays than on the weekends (Figure 2-7b). The number of sessions reaches a peak on Tuesday and starts a steady decline until it reaches a minimum number of sessions on Sunday. Tuesday and Wednesday had the most sessions for the period and represent 19% and 18% of user visits, respectively. Analysis of NOAA's Storm Events Database for the same timeframe also found that Tuesday had the highest number of events reported with 1295 events. Meanwhile, Sunday had the lowest number of events reported in NOAA's Storm Events Database with 993 events. Although it is unclear why a substantially different number of storm events were recorded on Tuesdays versus Sundays, it appears that the usage of OK-First (as measured by Google Analytics) is driven by the frequency of weather events, even on a daily basis over the course of the week.

c. Trends in the monthly use of the tools

An analysis of sessions on the Weather Briefing page revealed that peak web usage occurred between March and May. March reported the most sessions at 16% of the overall sessions (Figure 2-7c). The overlap of multiple weather hazards during March (e.g., wildfires, severe storms, and sometimes winter storms) likely contributed to it having the most sessions of any month in the year. The data are consistent with the NOAA Storm Events Database. The three months from March to May contributed 51% of all reported storms. The month of July had the lowest number of sessions representing only 5% of the total number of sessions.

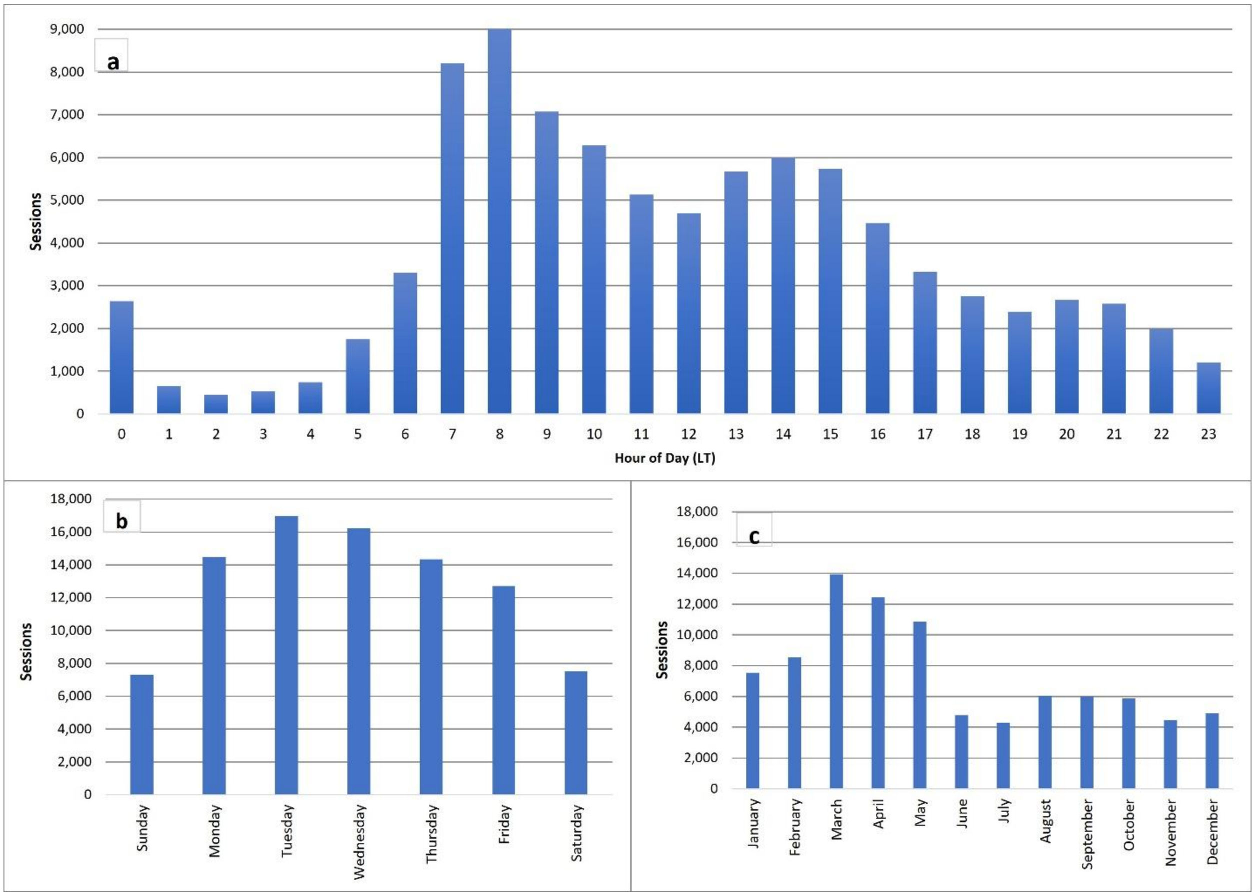

Figure 2-7: OK-First Weather Briefing page sessions by hour (a), sessions by day of the week (b), and sessions by month (c)

d. Assessment of highest use days

Data from Google Analytics reveal that the highest number of sessions for the OK-First Weather Briefing page was 897 sessions on 20 May 2019, corresponding with a high risk of severe storms, tornadoes, and flooding that day. The next three highest usage days between 2016 and 2020 were 30 April 2019, 26 April 2016, and 17 April 2019 which also corresponded with severe storms associated with risks of tornadoes, hail, and flooding. Spikes in data usage reinforced that public safety officials relied heavily on the OK-First Weather Briefing page to prepare for and manage high-impact events. Days with the lowest page views typically corresponded with weekends, holidays, or months outside of peak storm season.

2) NOAA'S STORM EVENTS DATABASE AND OK-FIRST WEATHER BRIEFING PAGE

In an effort to provide a detailed analysis of the correlation between the OK-First Weather Briefing page usage and actual storm events archived in the NOAA Storm Events Database, Figure 2-8 focuses on the March 2019 to April 2020 period. This 12-month period corresponds with the period survey respondents were asked to report their decisions made using the OK-First tools and training. Figure 2-8 shows a significant positive correlation between sessions recorded on the OK-First Weather Briefing page and weather events ($r = 0.7$, $p < 0.001$). This further reinforces that OK-First tool usage increases as impactful weather events increase. Generally, extreme weather events like tornadic storms and flash floods led to higher views on the OK-First Weather Briefing Page. A liner model was fitted to the data after outliers were removed. After removal of all outliers, 47% of the variation in weather events was explained by using the number of sessions as a predictor ($r = 0.5$, $p < 0.001$). These results are comparable to studies by Stadler and Fiebrich (2018) on web hits on the Oklahoma Mesonet.

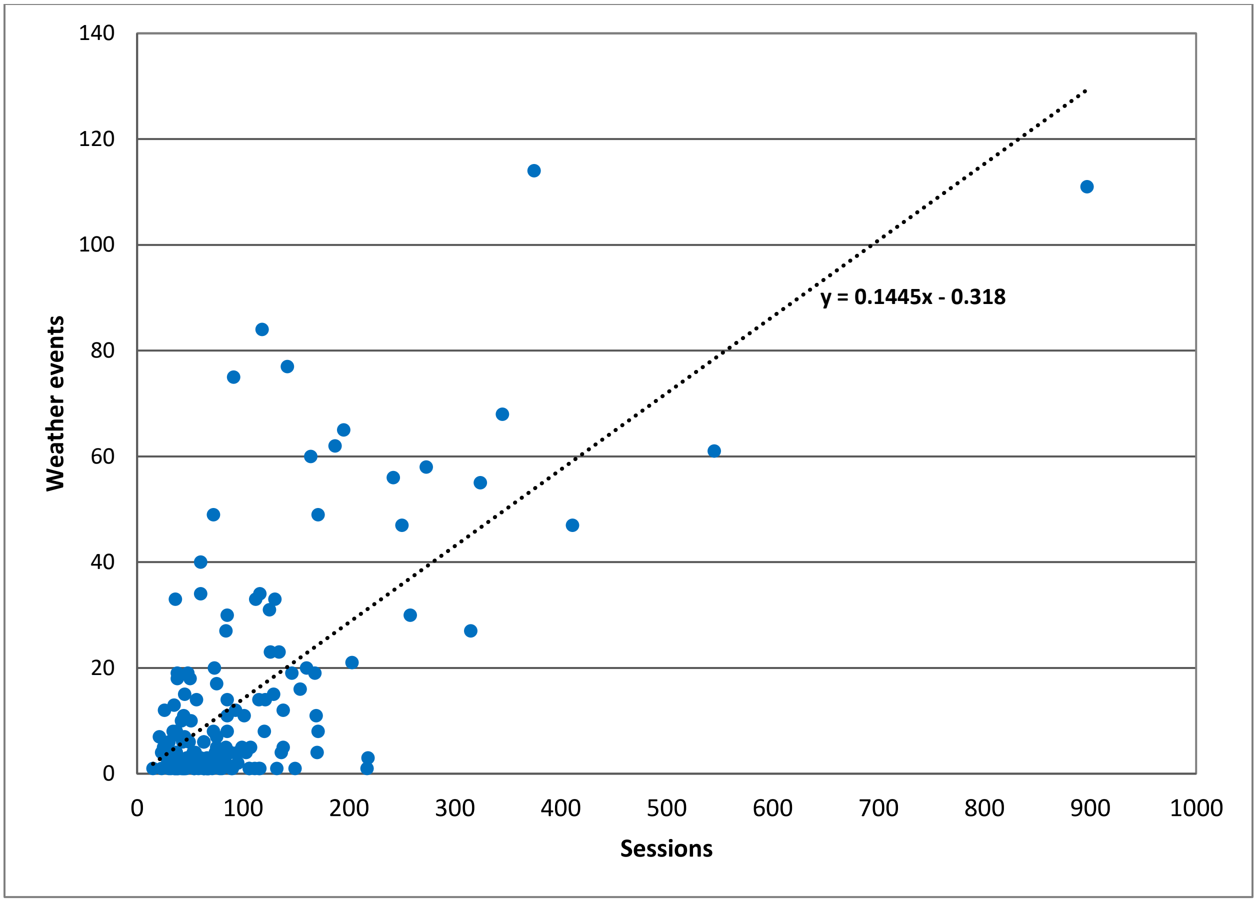

Figure 2-8: Scatterplot of reported weather events reported in the NOAA Storm Events Database and OK-First Weather Briefing page sessions from March 2019 to April 2020 in Oklahoma

2.4 Discussion

The long-standing history of the OK-First program provided an ideal opportunity to reveal a deeper understanding of the public safety community and their use of weather information (Baumgart et al. 2008; Baumgart and Bass 2006; James et al. 2000; Morris and Duvall 1999). It was found that public safety officials have different job roles, responsibilities, jurisdictions, training, tools available, responsibilities, and experience levels. Similar to Hoss and Fischbeck (2016), Weaver et al (2014), and Doswell (1999), it was found that public safety officials operate under varying organizational structures and different staff make-up including volunteers, parttimers, or retirees. For example, public safety officials often perform diverse roles they may not be trained for, such as coordinating rescue efforts or performing tasks such as supporting firefighters or directing traffic. Additionally, public safety officials join programs such as OK-First to find ways to collaborate with others and gain new tools and resources to prepare for disasters. For instance, over 90% of public safety officials felt that the training and technology provided by the OK-First program were very important in helping them to perform their various duties in their jurisdictions.

This research aimed to expand the results of Baumgart et al. (2008), who also studied decision-making by emergency managers. OK-First participants reported using OK-First tools to make various time-sensitive decisions to warn the public of threats, including severe weather. The daily use of OK-First tools, even in the absence of extreme weather, shows the importance of having continual access to trusted, high-quality weather information (Hoss and Fischbeck 2016; Weaver et al. 2014; Baumgart et al. 2008; 2006; Morss and Ralph 2007; Baumgart and Bass 2006). The decisions that OK-First participants made were diverse and included informing an official, coordinating with schools concerning weather-related closures, interrupting local television programming for emergency alerts, opening community storm shelters, communicating with first respondents, and activating tornado sirens. These results demonstrate that the OK-First program can enhance situational awareness and increase the ability of officials to make weather-related decisions. Over 85% of survey respondents reported making decisions for their jurisdictions based on OK-First training and tools. Similar to the findings of Hoss and Fischbeck (2016), OK-First participants indicated the importance of education and training, which led to confidence in making decisions.

Additionally, consistent with the findings of Stadler and Fiebrich (2018), analyzing Google Analytics data alongside weather event reports from NOAA's Storm Events Database provided valuable insights. These results show that decision makers use the tools most heavily on weather event days, which supports the views of previous studies that provided training, technology, products, and tools, public safety officials can utilize meteorological information to mitigate disasters and improve preparedness (Hunemuller 2010; Rayner et al. 2005; Penning-Rowsell et al. 2000; Golden and Adams 2000; Parker and Handmer 1998).

Research also suggests access to weather information has societal benefits. For example, Cho and Kurdzo (2020, 2019) argued that current radars in the conterminous US offer a tornado-based benefit of ~$490 million (M) yr^{-1}. There is a benefit estimate of $207 million (M) yr^{-1} relative to no radar coverage at all for non-tornadic storms. Accounting for and measuring the economic value of information, however, is a very challenging task (Ziolkowska 2018). The most effective method to estimate economic value depends on the type of information decision makers need, the information and expertise available, and the relevance to different groups – information users, decision makers, and advisors (Lawson 2019; Ziolkowska 2018). Moreover, it is sometimes helpful to use various economic analyses to assess data and information's economic value. Ziolkowska (2018) used a combination of current market value and utility value methodologies to quantify the economic value of Mesonet information in Oklahoma's agriculture sector for 2006 – 2014, while Klockow et al. (2010) used in-depth interviews to estimate the potential savings for farmers using Mesonet data. Lawson (2019) argued that economics could be applied beyond monetary costs and benefits or jobs and income. Lawson (2019) indicated that benefits can be monetized (e.g., dollars saved on heating costs), quantified (e.g., tons of emissions reduced), or qualitatively described (e.g., improved quality of life). This research used a self-reported approach to estimate the value of weather information and training provided by the OK-First program. The precise value was impossible to quantify perfectly because there was a non-discrete amount of savings reported by over 32% of survey respondents (e.g., those who indicated savings between $1,001 and $10,000 and those who reported savings over $10,000). Given that at least 16% of public safety officials estimated cost savings of over $10,000 for their jurisdictions, a conservative estimate is that the OK-First community (of which there are 812 members) made decisions with cost savings exceeding $1.2 M over a 1-year period. This estimate (equation 2-1) was based on 45 respondents who reported savings of at least $10,000.

$$S = \left(\frac{N_{10000}}{N}\right) \times P \times 10000 \qquad \text{(2-1)}$$

Where:

N_{10000} = *Number of respondents who reported savings of at least $10,000*

N = *Total number of respondents*

P = *Total number of active participants in the program*

This estimate does not capture savings made by participants who responded with savings between $1,000 and $10,000 nor does it capture specific savings greater than $10,000. This paper is a first step in estimating the value of information provided by weather decision programs such as the OK-First program. To fully explore the economic value of the OK-First program, however, non-market valuation techniques such as contingent valuation, avoided costs (averting behavior), or evaluation of the difference in value between the outcome realized with access to the OK-First system and the outcome realized without access to the OK-First system would be necessary.

2.5 Summary

Several key perceptions, beneficiaries, and applications of a weather decision support system for Oklahoma's public safety officials were revealed through surveys, Google Analytics, and the NOAA's Storm Events Database. Among the various findings, the following are the most significant based on the research questions. First, public safety officials consider the different products and tools provided by the OK-First program as very important to accomplish their roles in their various jurisdictions. Second, public safety officials reported using and integrating OK-First tools in their workflow on a daily basis. Third, although the Mesonet App was the most frequently used OK-First tool, there were geographic variations with OK-First tool use. Fourth, public safety officials took a diverse set of actions based on their access to the OK-First tools and data, with the most frequent being to inform decision makers. In fact, over 25% of respondents indicated making ten or more weather-related decisions for fire, severe weather, and winter weather during a 12-month period. Finally, self-reported cost savings based on decisions made by OK-First participants were estimated to be over $1.2M per year.

The roles of public safety officials in Oklahoma have evolved significantly, particularly with respect to managing Oklahoma's year-round threat of hazardous weather. With this evolution, there has been a shift from responding to events to preparing for and pre-planning for them. Overwhelmingly, the OK-First program has demonstrated that public safety officials can make well-informed decisions to protect life and property and save precious resources when adequately trained and provided with trustworthy and timely weather information. However, these dividends require a committed and sustained approach that is consistently funded to be successful. With the proper funding and requisite meteorological and technical expertise, other hazardous weather-prone states could reap cost-saving benefits similar to what Oklahoma has experienced over the last twenty-five years.

2.6 References

Baumgart, L. A., and E. J. Bass, 2006: Presenting information in simulated real-time to support part-task weather scenarios. Conference Proceedings - IEEE International Conference on Systems, Man and Cybernetics, Vol. 6 of, 5209–5214.

——, ——, B. Philips, and K. Kloesel, 2006: Emergency Management Decision-Making during Severe Weather. Proc. Hum. Factors Ergon. Soc. Annu. Meet., 50, 381–385, https://doi.org/10.1177/154193120605000336.

——, ——, ——, and ——, 2008: Emergency management decision making during severe weather. Weather Forecast., 23, 1268–1279, https://doi.org/10.1175/2008WAF2007092.1.

Cho, J. Y. N., and J. M. Kurdzo, 2019: Weather radar network benefit model for tornadoes. J. Appl. Meteorol. Climatol., 58, 971–987, https://doi.org/10.1175/JAMC-D-18-0205.1.

——, and ——, 2020: Weather radar network benefit model for nontornadic thunderstorm wind casualty cost reduction. Weather. Clim. Soc., 12, 789–804, https://doi.org/10.1175/WCAS-D-20-0063.1.

Doswell, C. A., A. R. Moller, and H. E. Brooks, 1999: Storm Spotting and Public Awareness since the First Tornado Forecasts of 1948. Weather Forecast., 14, 544–557, https://doi.org/10.1175/1520-0434(1999)014<0544:SSAPAS>2.0.CO;2.

Fiebrich, C. A., D. L. Grimsley, R. A. McPherson, K. A. Kesler, and G. R. Essenberg, 2006: The value of routine site visits in managing and maintaining quality data from the Oklahoma Mesonet. J. Atmos. Ocean. Technol., 23, 406–416, https://doi.org/10.1175/JTECH1852.1.

Friday, E. W., 1994: The Modernization and Associated Restructuring of the National Weather

Service: An Overview. Bull. Am. Meteorol. Soc., 75, 43–52, https://doi.org/10.1175/1520-0477(1994)0752.0.CO;2.

Golden, J. H., and C. R. Adams, 2000: The tornado problem: Forecast, warning, and response. Nat. Hazards Rev., 1, 107–118, https://doi.org/10.1061/(ASCE)1527 -6988(2000)1:2(107).

Gruntfest, E., 1998: Internet and Emergency management: Prospects for the Future. Int. J. Mass Emerg. Disasters, 16, 55–72.

Hasan, L., A. Morris, and S. Probets, 2005: Using Google Analytics to Evaluate the Usability of E-Commerce Sites. 697–706 pp.

Hocker, J. E., A. D. Melvin, K. A. Kloesel, C. A. Fiebrich, R. W. Hill, R. D. Smith, and S. F. Piltz, 2018: The evolution and impact of a meteorological outreach program for public safety officials : An update on the Oklahoma mesonet's ok-first program. Bull. Am. Meteorol. Soc., 99, 2009–2024, https://doi.org/10.1175/BAMS-D-17-0100.1.

Hoss, F., and P. Fischbeck, 2016: Increasing the value of uncertain weather and river forecasts for emergency managers. Bull. Am. Meteorol. Soc., 97, 85–97, https://doi.org/10.1175/BAMS-D-13-00275.1.

Hunemuller, T. J., 2010: Review and analysis of the National Weather Service river forecasts for the June 2008 eastern Iowa floods. University of Iowa, https://ir.uiowa.edu/cgi/viewcontent.cgi?article=2006&context=etd.

James, T. E., P. O. Long, and M. . Shafer, 2000: An independent evaluation of the OK-FIRST decision-support system. Amer. Meteor. Soc, 40–47.

Kent, M. L., B. J. Carr, R. A. Husted, and R. A. Pop, 2011: Learning web analytics: A tool for strategic communication. Public Relat. Rev., 37, 536–543, https://doi.org/10.1016/j.pubrev.2011.09.011.

Klockow, K. E., R. A. Mcpherson, and D. S. Sutter, 2010: On the economic nature of crop production decisions using the oklahoma mesonet. Weather. Clim. Soc., 2, 224–236, https://doi.org/10.1175/2010WCAS1034.1.

Lawson, M., 2019: Using Economics to Support Climate Adaptation. https://headwaterseconomics.org/equity/climate-change/economics-climate-adaptation/ (Accessed October 4, 2020).

Lusk, C., T. Stewart, K. Hammond, and R. Potts, 1990: Judgment and decision making in dynamic tasks- The case of forecasting the microburst. Weather Forecast., 5, 627–639.

McLoughlin, D., 1985: A Framework for Integrated Emergency Management. Public Adm. Rev., 45, 165, https://doi.org/10.2307/3135011.

McPherson, R. A., and Coauthors, 2007: Statewide monitoring of the mesoscale environment: A technical update on the Oklahoma Mesonet. J. Atmos. Ocean. Technol., 24, 301–321, https://doi.org/10.1175/JTECH1976.1.

Morris, D. A., and C. Duvall, 1999: Real-time, An evaluation of the use of weather data by public-safety agencies. Preprints, 15th Int. Conf. on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology, 380–383.

——, K. C. Crawford, K. A. Kloesel, and J. M. Wolfinbarger, 2001: OK-FIRST: A meteorological information system for public safety. Bull. Am. Meteorol. Soc., 82, 1911–1923, https://doi.org/10.1175/1520-0477(2001)082<1911:OFAMIS>2.3.CO;2.

——, ——, ——, and G. Kitch, 2002: OK-FIRST: An example of successful collaboration between the meteorological and emergency response communities on 3 May 1999. Weather Forecast., 17, 567–576, https://doi.org/10.1175/1520-0434(2002)017<0567:OFAEOS>2.0.CO;2.

Morss, R. E., and F. M. Ralph, 2007: Use of Information by National Weather Service Forecasters and Emergency Managers during CALJET and PACJET-2001. Weather Forecast., 22, 539–555, https://doi.org/10.1175/WAF1001.1.

Parker, D. J., and J. W. Handmer, 1998: The role of unofficial flood warning systems. J. Contingencies Cris. Manag., 6, 45–60, https://doi.org/10.1111/1468-5973.00067.

Penning-Rowsell, E. C., S. M. Tunstall, S. M. Tapsell, and D. J. Parker, 2000: The Benefits of Flood Warnings: Real But Elusive, and Politically Significant. Water Environ. J., 14, 7–14, https://doi.org/10.1111/J.1747-6593.2000.TB00219.X.

Petak, W. J., 1985: Emergency Management: A Challenge for Public Administration. Public Adm. Rev., 45, 3, https://doi.org/10.2307/3134992.

Phippen, A., L. Sheppard, and S. Furnell, 2004: A practical evaluation of Web analytics. Internet Res., 14, 284–293, https://doi.org/10.1108/10662240410555306.

Rayner, S., D. Lach, and H. Ingram, 2005: Weather forecasts are for wimps: Why water resource managers do not use climate forecasts. Clim. Change, 69, 197–227, https://doi.org/doi:10.1007/s10584-005 -3148-z.

Shafer, M. A., C. A. Fiebrich, D. S. Arndt, S. E. Fredrickson, and T. W. Hughes, 2000: Quality assurance procedures in the Oklahoma Mesonetwork. J. Atmos. Ocean. Technol., 17, 474–

494, https://doi.org/10.1175/1520-0426(2000)017<0474:QAPITO>2.0.CO;2.

Stadler, S. J., and C. A. Fiebrich, 2018: Web Hits on the Oklahoma Mesonet. American Association of Geographers Annual meeting 2018, New Orleans, LA, https://aag.secure-abstracts.com/AAG%20Annual%20Meeting%202018/abstracts-gallery/12811.

Uccellini, L. W., and J. E. Ten Hoeve, 2019: Evolving the National Weather Service to Build a Weather-Ready Nation: Connecting Observations, Forecasts, and Warnings to Decision-Makers through Impact-Based Decision Support Services. Bull. Am. Meteorol. Soc., 100, 1923–1942, https://doi.org/10.1175/BAMS-D-18-0159.1.

Waugh, W. L., 1994: Regionalizing Emergency Management : Counties as State and Local Government. Am. Soc. Public Adm., 54, 253–258.

Weaver, J., L. C. Harkabus, J. Braun, S. Miller, R. Cox, J. Griffith, and R. J. Mazur, 2014: An overview of a demographic study of united states emergency managers. Bull. Am. Meteorol. Soc., 95, 199–203, https://doi.org/10.1175/BAMS-D-12-00183.1.

Ziolkowska, J. R., 2018: Economic value of environmental and weather information for agricultural decisions – A case study for Oklahoma Mesonet. Agric. Ecosyst. Environ., 265, 503–512, https://doi.org/10.1016/j.agee.2018.07.008.

Ziolkowska, J. R., and Coauthors, 2017: Benefits and beneficiaries of the Oklahoma mesonet: A multisectoral ripple effect analysis. Weather. Clim. Soc., 9, 499–519, https://doi.org/10.1175/WCAS-D-16-0139.1.

Chapter 3: Economic Value of a Weather Decision Support System for Oklahoma Public Safety Officials

Abstract

The Oklahoma Mesonet's Public Safety outreach program, called OK-First, has provided weather education and data delivery to the public safety community for the past 25 years. By delivering high-quality weather data tools, regular classes, and continued follow-up support to its trained members, the OK-First program has empowered over 1800 public safety officials. Testimonials from OK-First users show that there is an immense value in providing nonscientific audiences with meteorological information and training. OK-First users have reported making decisions to save lives and property using the OK-First program. However, there has been no quantitative analysis that evaluates the value of the OK-First program. This study fills a gap in providing quantitative analysis for the economic value of the OK-First program. This research used a modified travel cost method (TCM) to value information provided by the OK-First program to the users of the program. Results show that the average willingness to pay for the OK-First is $1,122 per training. The OK-First program in Oklahoma is valued at an estimated $254,000, with a collective surplus of $80,000 per training for OK-First users. This conservative estimate suggests the importance of programs such as the OK-First training, especially for public safety officials in Oklahoma.

Keywords: Oklahoma Mesonet, Weather Decision Support, Oklahoma, Public Safety Officials, Economic value, Non-market valuation, Travel Cost Method

3.1 Introduction

The demand for accurate and timely meteorological information has increased and is anticipated to grow even more in the future, especially in times of extreme weather events. (Ziolkowska et al. 2017; Mahmood et al. 2017; Fiebrich 2009). As a result, automated weather monitoring technologies were developed in the 1970s to meet the growing demands of timely weather data (Brock and Govind 1977; Brock et al. 1986). An essential aspect of this growth was developing spatially dense networks with sub-hourly (e.g., with resolution up to 5 minutes) observations in the 1980s and 1990s (Mahmood et al. 2017). Many weather monitoring networks initially had a primary purpose of collecting data for agricultural applications (including forestry), but applications have expanded to various purposes including air pollution and military operations (Tucker 1997).

The Oklahoma Mesoscale Network is an example of a weather network that paved the way from agricultural use to much broader applications, including public safety, climate monitoring, and energy usage (Crawford et al. 1998; McPherson et al. 2007). The Mesonet has served as a model network for the establishment of other weather monitoring networks across the United States and abroad because of data accuracy, consistency, validation, and the maintenance of nearly-complete records (Ziolkowska et al. 2017; Fiebrich 2009; McPherson et al. 2007; Fiebrich et al. 2006; Shafer et al. 2000). The availability of near real-time and high-quality data provided by automated weather networks create opportunities for educated and effective decision-making processes, research, and policy design on a diverse set of topics throughout the country (Na-Yemeh et al. 2020; Mahmood et al. 2017).

The Oklahoma Mesonet (OK Mesonet) has numerous applications and uses across Oklahoma and beyond (Ziolkowska et al. 2017). The OK Mesonet provides products and services, such as real-time and historical weather data, weather data drought monitoring, climate monitoring, public safety tools, and fire management tools, to Oklahoma general public, private business, and public agencies that generate economic, environmental, and social benefits (Ziolkowska et al. 2017; Klockow et al. 2010; Carlson and Bidwell 2008). The most notable sectors that the OK Mesonet information influences are weather forecasting, agriculture, education, emergency management, wildlife and fire management, energy industry, transportation, and scientific research (Oklahoma Mesonet 2020). The benefits of the OK Mesonet information can be grouped into three major branches: 1) research and education, 2) environmental (such as protection of landscapes and habitats), and 3) safety (such as emergency, wildfire, and transportation management). The OK Mesonet generated information and products and services provided are public goods. Understanding and quantifying the benefits of OK Mesonet generated information aids stakeholders and policymakers in decisions (or decision-making) on fiscal funding allocations for maintaining and expanding products and services.

This research focuses on OK Mesonet generated information value to public safety officials (PSOs) in Oklahoma. PSOs, such as emergency managers, play a critical role in storm-prone areas like Oklahoma (Baumgart et al. 2008). Located in the south-central (tornado alley) part of the United States (U.S.), Oklahoma is prone to severe weather events like thunderstorms, droughts, floods, and tornadoes. Because 78% of all emergency management concerns nationwide are weather-related, PSOs end up serving as "*messengers*" of the National Weather Service (NWS) and make decisions using information from multiple resources to save lives and property (Hoss and Fischbeck 2016; Weaver et al. 2014; Morss and Ralph 2007). PSOs across the state use Oklahoma's First Response Information Resource System (OK-First, hereafter) to help make decisions to save lives and property. The OK-First program is one of the outreach programs of the

OK Mesonet. The OK-First program provides Oklahoma's PSOs with weather education and critical real-time weather data (Hocker et al. 2018; Morris et al. 2002, 2001).

PSOs receive education and training from the OK-First, resulting in increased situational awareness of weather and the ability to make weather-related decisions for their jurisdictions (Na-Yemeh et al. 2022). The OK-First users had shared testimonials of making life-saving decisions using the OK-First data (Hocker et al. 2018; Morris et al. 2002). Using OK-First data, PSOs made decisions to close bridges during floods, save property in wildfires, improve evacuations after hazardous spills, and protect audiences at outdoor events. The OK-First program has also enabled the efficient scheduling of public works, projects, and information for police and fire investigations (Hocker et al. 2018; Morris et al. 2002).

The direct benefits and widespread impact of OK-First training include increased awareness about upcoming weather events, enhancing public safety, and improving individual weather decision-making (Golden and Adams 2000; Riebsame et al. 1986). For emergency managers, heightened awareness means saving more lives and protecting valuable resources such as cultural ecosystem services, tourism destinations, and recreational activities. Ziolkowska et al. (2017) identified several benefits and beneficiaries of the OK-First program. Still, the authors recognized a need for future quantitative studies of the benefits resulting from this program for different sectors and user groups. This research used a modified travel cost method (TCM) to estimate the economic values of the OK-First training program to PSOs in Oklahoma. To achieve the goal of providing a quantitative analysis for the economic value of the OK-First program, the study answers the following research questions:

1. What is the economic value of the OK-First program?
2. What is the average Willingness Travel Cost (*TCW*) per training?

3. What is the collective surplus *TCW* generated by the OK-First program?

3.2 Previous Research on Economic Valuation of Information

Accounting for and measuring the economic value of information of any kind and in any discipline is a very challenging task (Ziolkowska 2018). There is currently no generally accepted approach to measure the value of information (Moody and Walsh 1999). The main reason for this difficulty arises from quantifying the value of information using monetary terms. Therefore, accounting for the value of information needs to occur indirectly, based on other tangible (measurable) variables (Ziolkowska 2018). As a result, Moody and Walsh (1999) argue that information has no real value on its own; instead, it only becomes valuable when there is a demand for it. The potentially appropriate theoretical measure of economic benefits could be assessed based on the changes in welfare due to the event (and in our study, the OK-First program for emergency management) (Rose 2015).

The most effective method in valuing information depends on the types of information expertise availability, and the relevance to user groups (Lawson 2019; Ziolkowska 2018). Stewart et al. (2003) concluded that there is a potential societal value of improved weather forecasts and the need for research to work towards this realization. The authors argue an excellent starting point to ensure this realization is a detailed understanding of user needs and decision-making processes. Letson et al. (2007) recognized that to appreciate user needs and decision processes, the economic value of information should be deliberated. For example, when the meteorological community was provided with data and methods necessary for improved knowledge base of forecasts, use, and value, decisions can be made to prepare for disasters (Letson et al. 2007; Stewart et al. 2004). The information on user needs will inform forecasters how to adapt to technology and incorporate new knowledge into their forecast process (Morss and Ralph 2007).

The travel cost method (TCM) is a non-market procedure that dates back to the 1930s when Harold (1936) estimated economic values for railway and utility services. The TCM uses revealed preference as opposed to stated preference where participants are explicitly asked to state their Willingness to Pay (WTP) (Boyle 2003). Multiple applications of TCM have allowed this environmental valuation approach to be applied to research outside of traditional applications, such as environmental education at a destination. Legg (2020) used TCM to estimate the value of environmental education for adults throughout the state of Oklahoma. In this case, travel cost was used as a proxy for what participants pay or were willing to pay and would potentially pay in addition to access environmental education (Legg 2020). Environmental education is more than just information about the environment (EPA 2020). The EPA defines it as *"a process that allows individuals to explore environmental issues, engage in problem-solving, and take action to improve the environment. As a result, individuals develop a deeper understanding of environmental issues and have the skills to make informed and responsible decisions"*. Therefore, non-market valuation method is appropriate approach to estimate the economic value of information and environmental education.

Nonetheless, the environment as a good does not function as a commodity but as a service (Sander and Haight 2012). Researchers thus consider the environment as a "cultural ecosystem" during analysis. Hutcheson et al. (2018) used this principle to estimate the economic value of Hudson River Park's environmental education program.

This study thus used a modified TCM approach to evaluate economic value of the OK-First training program for public safety officials in Oklahoma. Here, the training and resources they receive are considered comparable to those received in environmental education and thus a cultural ecosystem service. The results of this study in magnitude were not similar to more traditional applications of TCM to world-renowned recreational sites and tourist attractions. For example, the estimated consumer surplus of the Poseidon temple in Sounio, Greece, was €1.5-24.5 million per year (Tourkolias et al. 2015). The study provided valuable insights into the amount of money that was socially acceptable to be spent by the Greek state to maintain and protect the monument. Similarly, Chen et al. (2004) used TCM to support the implementation of suitable fees to protect tourism resources by estimating the value of a beach and its associated recreation to be over $53 million.

TCM can be similarly applied to validate the allocation of public funding of programs such as OK-First. A distinction between OK-First and sites that attract visitors from across the globe is the magnitude of their estimated consumer surplus, such as the Poseidon temple with a consumer surplus in the range of millions of dollars. Other studies that focus on less famous study sites tend to be more monetarily comparable to the results of this study on the economic value of OK-First Training, which is only open to public safety officials within the boundaries of the state of Oklahoma. For example, Anderson (2010) estimated the economic value (demand) for ice climbing in Hyalite Canyon, Montana, to be within $76 to $480 per year per average individual. Similarly, Coupal et al. (1999) used TCM to estimate consumer surplus values to determine its economic benefits. The authors examined the characteristics, preferences, and motivations for snowmobiling of Wyoming Snowmobilers for the study. The consumer surplus per trip for the pooled sample was $68, and the different market segments ranged from $31 to $101 per trip. The review of traditional applications of TCM indicates the wide range of estimated values for sites and amenities across the globe.

3.3 Methods and data

3.3.1 *Data collection and sources*

A survey was developed in collaboration with stakeholders in the field of emergency management in Oklahoma. A pilot survey was tested and vetted by the OK-First Advisory Committee. The survey design included both closed and open-ended questions to provide the needed data to calculate individual and aggregate travel costs. I asked what the participant actually paid to attend an event and what the participant would be willing to pay to participate in the event regarding travel, time, and other expenditures. A question on job role and position was asked to estimate the income for each respondent.

After obtaining Institutional Review Board approval (#11814), an anonymous survey link was then distributed to 812 OK-First program users between 3 April – 11 May 2020. I received 280 completed surveys and 257 were used after eliminating surveys with missing or unclear data.

3.3.2 *Data*

Table 3-1 shows the variables that are used in the TCM calculation. Each variable accounts for either a TCM calculation component or for reporting information about OK-First participants.

Table 3-1: Variables included in the survey given to participants.

Variables	Definition
TCA	Costs of travel to OK-First program training venue
TCW	Expected cost of travel based on participants' travel costs and stated willingness to travel farther to OK-First program venues
d	Round trip travel distance (miles)
t	Round trip travel time (hours)
d^w	Reported WTT to travel farther to attend training added to actual travel distance multiplied by two to represent round trip travel distance (miles)
t^w	Estimated round trip time based on willingness to travel farther and the rate at which the participant actually traveled in hours (hours)
c	U.S. General Services Administration Privately owned vehicle automobile rate per mile for January 1, 2020, of $0.575
e	Duration of event based on level of certification (hours)
o	Other reported expenditures such as toll fees, lodging costs, food in U.S. Dollars (2020)
c	Reported number of OK-First classes 1-5 years = 1, 6 -10 years = 2, 10 - 15 years = 3 16 - 20 years = 4, 20+ years = 5.
m	The estimated median income in U.S. dollars based on the participants' job classification chosen.
s	Self-reported savings Below $1,000 = 1, $1,001-$5,000 =2, $5001-$10,000 =3, over 10,000 =4, Unsure =5
f	Decisions made on flooding within a year using OK-First training. 1-5times = 1, 6 – 10 times = 2, More than 10 times =3

The job role and position each respondent identified and their income levels per hour are presented in Table 3-2. Over half of the respondents identified as either emergency managers, fire officials, or law enforcement. This diverse group of users collectively represents no one job type but rather a broader set of positions fitting under the umbrella term "public safety officials."

Table 3-2: Roles and hourly income levels of OK-First survey participants (n=257)

Role and Position	**Percentage**	**Income level per hour**
1.Emergency manager	39%	$24.55
2.Law enforcement	15%	$21.95
3.Fire official	12%	$20.59
4.911/Dispatcher	8%	$19.20
5.Other	7%	$15.30
6.City official	4%	$24.55
7.Emergency medical responder	3%	$17.01
8.Non-profit volunteer organization Active in Disaster	3%	$17.02
9.School official	3%	$15.00
10.Tribal official	2%	$24.55
11.County official	1%	$24.55
12.State official	1%	$24.55
13.Health official	1%	$18.55

The survey received 257 responses. Among them, 59% had been in OK-First for one to five years, 23% had been in the program for six to ten years, and 18% had been in the program for more than ten years. Because OK-First participation is contingent on current employment in public safety positions, retirements, career changes, and other factors have contributed to individuals leaving the program. For OK-First class attendance, approximately 67% of respondents attended one to five OK-First classes, 22% attended six to ten classes, and 11% attended more than ten classes. Additionally, 76% of responses have participated in the week-long OK-First certified classes. Twenty-four percent of respondents are OK-First Assistant certified, which is a 2-day class.

Because the data obtained from the survey responses did not directly address all necessary components (i.e., hourly wages, mileage) of the travel cost calculations, estimations and inferences were made from the available data in the literature. Based on the responses to questions about user occupations, hourly wage was estimated for each participant based on data from the occupational employment and wage statistics of the U.S. Bureau of Labor Statistics for the state of Oklahoma and the Oklahoma Watch database (U.S. Bureau of Labor Statistics 2020). From this, it was assumed that individuals traveled during work hours or were being paid for the time they took to obtain OK-First training, so the opportunity cost of time included the individual's total estimated hourly wage rate. To account for mileage, it was assumed that individuals were travelling alone in a vehicle such as a car, SUV, truck, or van and that the mileage and operating costs were $0.575 per mile (Vehicle Rates 2020). Table 3-3 shows the summary statistics of the variables used for TCM calculations.

Table 3-3: Summary statistics of variables.

Variable	**Variable Description**	**Unit**	**Mean**	**Std Dev**	**Min**	**Max**
TCA	Actual Travel Cost	U.S. $	811	372	68	2123
TCW	Willingness to Pay	U.S. $	1122	445	179	2483
d	Actual Round Trip Distance	miles	149	108	4	500

Variable	Variable Description	Unit	Mean	Std Dev	Min	Max
t	Actual Round Trip Travel Time	hours	2	2	0.1	8
d^w	Willingness Round Trip Distance	miles	489	224	200	1200
t^w	Willingness Round Trip Time	hours	8	4	3	19
e	Time at Event	hours	21	5	12	24
t	Time cost	U.S. $	440	158	0	589
o	Other Reported Expenditures	U.S. $	235	263	0	1560
c	Number of OK-First classes	Classes	2	1	1	5
w	Wage	U.S. $	21	3	15	25

3.3.3 *Travel Cost Calculation*

This study used the travel cost method to estimate what participants paid and were willing to pay to access the OK-First training and the individual choices associated with a willingness to pay more. Participation in the OK-First program is competitive, restricted to officials with public safety responsibilities (for-profit entities are not eligible), and dependent on successful completion of a four-day OK-First Certification class (Hocker et al. 2018). As such, the conventional approach to TCM that estimates the probability of a number of visits to a specific location over time was not used to evaluate OK-First because once a member became certified in the OK-First program, they were required to attend recertification classes no less than once every 18 months. Each participant's costs associated with travel, such as distance traveled, time commitment, and other fees, were incorporated into the calculation for what they pay and are willing to pay for OK-First training.

Aggregate travel costs for each participant were calculated based on the conventional TCM calculation by Parsons (2003) and adapted to educational events by Legg (2020). It encompasses all the costs associated with access and travel to OK-First training for each individual i (Equation 3-1). A second equation addressed the willingness travel costs for each individual and encompassed the participant willingness to travel farther, inferring their willingness to pay more (Equation 3-2).

$$TCA_i = p_i^a + l_i + e_i + f_i + o_i \tag{3-1}$$

$$TCW_i = p_i^w + l_i + e_i + f_i + o_i \tag{3-2}$$

Where p^a refers to participant actual cost or price of travel, p^w participant willingness cost or price of travel, *l*: reported lodging costs, e: time cost at event (time cost is the participants' hourly wage multiplied by the number of hours spent at the educational event), *f* is the cost of food, *o r*efers to other reported costs.

The implicit and explicit costs associated with attending the event itself were uniform for each individual for both the actual and willingness travel cost calculations (i.e., the registration fee, lodging, and time cost at the event were unchanged between the two calculations). Because the WTP was calculated based on the question regarding willingness to travel farther in the journey, equations to account solely for the components of actual and willing costs associated with journey were expressed. These individual costs of travel, p, were calculated twice. The first calculation (p^a) addressed what the participant actually paid to travel to the training based on the round-trip distance and time actually traveled (Equation 3-3). Equation 3-4 is the second calculation (p^w) for participants' inferred willingness to pay based on the reported distance that the individual was willing to travel past the actual distance they traveled based on the response to the survey question:

“*If you had to travel further for OK-First classes, how many more miles would you be willing to travel?*”.

$$p_i^a = \{(m_i \times t_i)\} + \{(c_i \times d_i)\} + tolls_i \quad (3\text{-}3)$$

Where m_i is the individual hourly income, t_i is the round-trip travel time, c_i is the vehicle operating costs per mile. d_i is the round-trip travel distance, $tolls_i$ is the tolls paid on the journey for training.

$$p_i^w = \{(m_i \times t_i^w)\} + \{(c_i \times d_i^w)\} + tolls_i \quad (3\text{-}4)$$

Where m_i is the individual hourly income, t_i^w is the round-trip travel time for additional distance, c_i is the vehicle operating costs per mile. d_i is the additional willingness round trip travel distance beyond what was actually travelled, $tolls_i$ is the reported tolls paid on the journey for training.

An aggregate travel cost calculation expressed what the entire participant sample collectively paid and were willing to pay to access OK-First training. The aggregate travel cost equation totaled what all $n = 257$ participants paid (Equation 3-5) and were willing to pay (Equation 3-6) to access OK-First training.

$$TA = \sum_{i=1}^{n} TCA_i \quad (3\text{-}5)$$

$$TW = \sum_{i=1}^{n} TCW_i \quad (3\text{-}6)$$

Where TCA is the aggregated individual actual travel costs overall participants i and $i = 1, \dots, 257$, TCW is the aggregated individual willingness to pay travel costs for all participants i.

3.3.4 *Estimation of Consumer Surplus*

Equation 3-7 is the aggregate consumer surplus. The surplus is calculated by deducting the total actual costs (equation 3-5) from the total willingness to pay (equation 3-6) for the cost of travel reported by OK-First users.

$$\text{Surplus}_{\text{individual}} = \sum_{i=1}^{n} TC_{willingness} - \sum_{i=1}^{n} TC_{actual} \quad (3\text{-}7)$$

Equation 3- 8 and Equation 3-9 were used to create a set of demand curves to estimate the value of OK-First training and information to the OK-First community. The calculation expressed the difference (Equation 3-10) of what the entire participant sample collectively paid and were willing to pay to access OK-First training. The estimation of the surplus is important because this provides the estimate the value of information using the derived demand curve.

$$TCA = \alpha + \beta \ln{(r^A)} \qquad (3\text{-}8)$$

$$TCW = \alpha + \beta \ln{(r^W)} \qquad (3\text{-}9)$$

Where r is the participant percentiles for the actual costs and willingness costs.

$$TCW - TCA = \int_0^1 (a \ln(TCW) + b)\, dTCW - \int_0^1 (c \ln(TCA) + d)\, dTCA \qquad (3\text{-}10)$$

Where $TCW - TCA$ is the differential of willingness curve and actual individual aggregate travel costs, n=257 participants.

3.3.5 *Decision Tree Analysis*

The conventional TCM approach to creating an econometric model was not applicable to this study. TCM utilizes techniques such as variants of the Poisson count data model to estimate the probability of visits to a particular site over an interval of space or time. Other studies involved multiple sites with singular visits (Legg 2020; Parsons 2003). A decision tree analysis (Equation 3-11) was performed to show participants' willingness to pay beyond a dollar amount to access OK-First. This was used to show how selected predictor variables accounted for a more significant willingness to travel further for OK-First training.

$$y = d + c + s + f \qquad (3\text{-}11)$$

Where y is the willingness to pay for extra travel, d is the round trip distance travelled in miles, c is the number of OK-First classes participants have taken, s is the self reported savings OK-First users reported by using OK-First training and f is the number of times participants have made decisions based on floods.

The general approach of decision tree analysis is to produce a binary tree. Each tree node represents a binary division of the data present at that node, determined by some statistical criterion such as least squares (Roff and Roff 2003). Each node is considered separately and analyses all the available predictor variables; thus, for example, at the first split, the data may be best divided according to one predictor variable while at a subsequent node, the best split of the data passing through that node may be accomplished using another predictor variable (Roff and Roff 2003). Regression trees should be viewed as hypothesis-generating routines rather than hypothesis-testing routines. This approach has several important attributes: 1) the decision tree is easy to interpret when the predictors consist of both categorical and continuous variables; 2) the decision tree is invariant to monotone transformations of the predictor variables; 3) the decision tree can capture nonadditive behavior and allow very general interactions between predictor variables (Roff and Roff 2003). For further discussions on regression trees and Conditional Inference Trees, see Hothorn et al. (2015) and De'ath and Fabricius (2000). De'ath and Fabricius (2000) provide an excellent example of the method applied to community data.

A decision tree model was used in the analysis of variables such as the number of years in the OK-First program, the number of classes taken, and the types of weather decisions made using OK-First training. The model shows the significant values indicated by *p-values* in the nodes. The results yielded four decision clusters focused on four factors (round-trip mileage travel distance, self-reported savings, decisions based on flooding and the number of OK-First classes participants have attended) and resulted outcomes associated with OK-First users' WTP.

3.4 Results

3.4.1 *Economic Value and Travel Cost Model Output*

Based on the data collected using participant surveys of active OK-First members the average OK-First user was willing to pay \$312 beyond travel costs to access the OK-First training program. Actual cost of travel (p_i^a) to access OK-First training for n = 257 participants ranged from \$4.00 to \$462.00 for OK-First users. Participants paid an average of \$136 and a total of \$34,907 in travel costs p_i^a to access OK-First training. Participants paid a collective monetary value of \$208,484 to access OK-First training based on the costs of travel (TCA) such as distance traveled, vehicle operating costs, lodging costs, and time spent at the event. Additionally, participants spent an average of \$811 in travel costs (TCA), with expenses ranging from \$68 to \$2,123. The registration cost of attending OK-First is free to the participant. It is worth noting that the OK-First office usually provides a very limited number of travel scholarships (usually five per season) to their in-person certification class. That includes hotel and per diem and is provided as a reimbursement after the training. The extent of reimbursement for surveyed participants was unknown for this study.

Willingness to travel farther served as a proxy for participants' willingness to pay more to access OK-First training. Based on the question, "*If you had to travel further for OK-First classes, how many more miles would you be willing to travel?*" and the respondents' answer to this question, the participant's willingness to pay was calculated. Willingness to travel (p_i^w) for OK-First training ranged from \$164 to \$ 1,108. Participants were willing to pay an average of \$447 in cost of travel (p_i^w) to access OK-First training. Collectively, participants were willing to pay a total of \$114,886 to access this training. Willingness to travel costs (TCW) for OK-First training ranged from \$179 to \$ 2,483. Participants were willing to pay an average of \$1,122 in travel costs

(TCW) to access OK-First training. The collective total willingness to travel costs for participants was approximately $288,000.

Assumptions for regression analysis were checked and met. These include the error terms of the population ε_i are independent and identically distributed (iid) with an expected value of zero and a constant variance σ^2.

$$\varepsilon_i \sim iid\ (0, \sigma^2)$$

See Appendix E for Regression Model Diagnostics.

Based on the paired data of actual individual cost of travel and individual willingness to pay for each participant, it was estimated that participants would be willing to pay approximately $168 plus $2 for every dollar spent on accessing OK-First training (Figure 3-1).

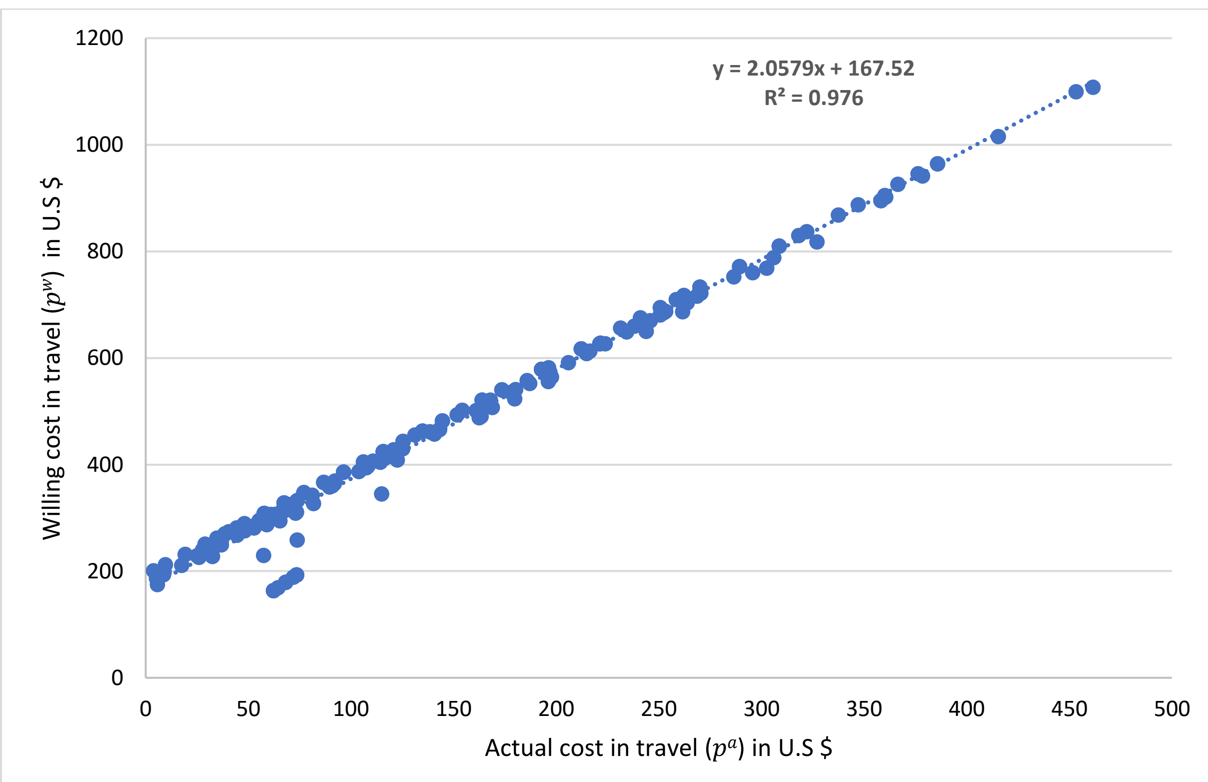

Figure 3-1: Relationship between individual actual costs and individual WTP (n = 257)

Figure 3-2 shows the paired data of individual actual travel cost and individual willingness travel cost for participants. It was estimated that participants were willing to pay approximately $171 plus $1 for every dollar spent on all expenditures to access OK-First training.

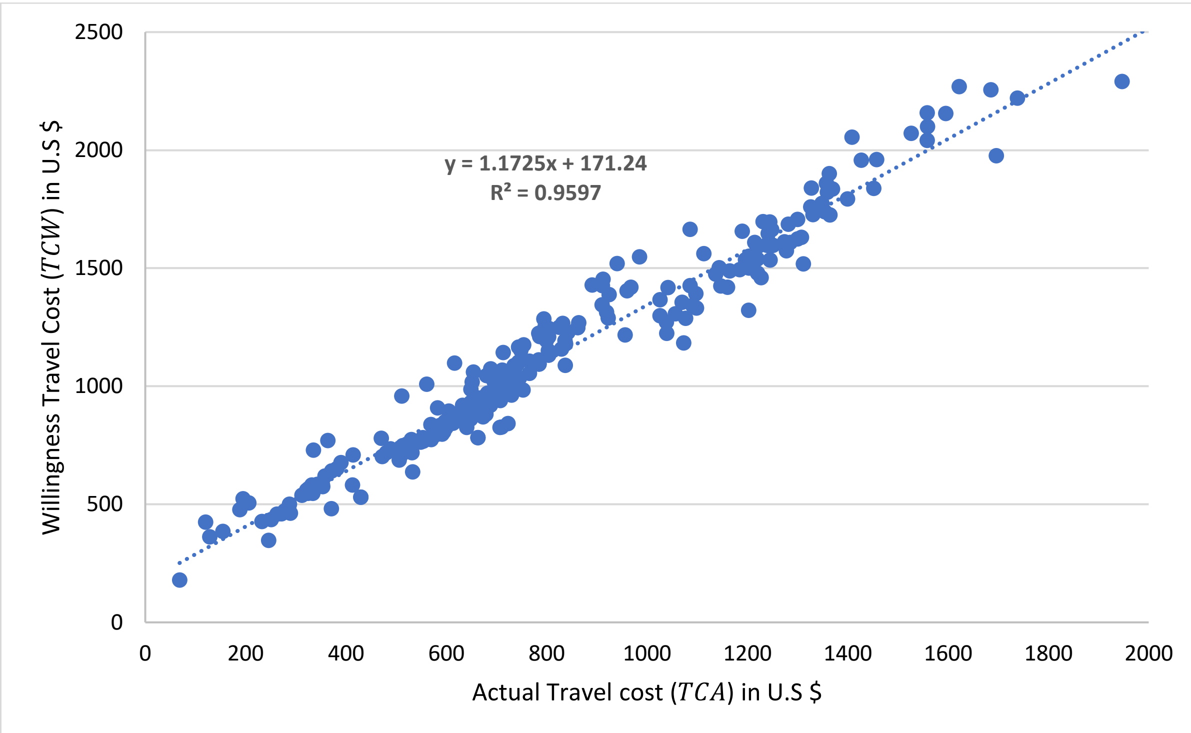

Figure 3-2: Relationship between individual actual travel costs and individual willingness to travel cost (n = 257)

Figure 3-3 analyzes the relationships between miles traveled, and actual and willingness travel costs. Results show a significant correlation (TCA: $\rho = -0.57$ and TCW: $\rho = -0.71$. However, only 30% of TCA could be attributed to miles from training, and 50% of TCW to travel could be attributed to how far participants had to travel - indicating that miles to OK-First training was not an indicator of participants' likelihood to travel for OK-First training.

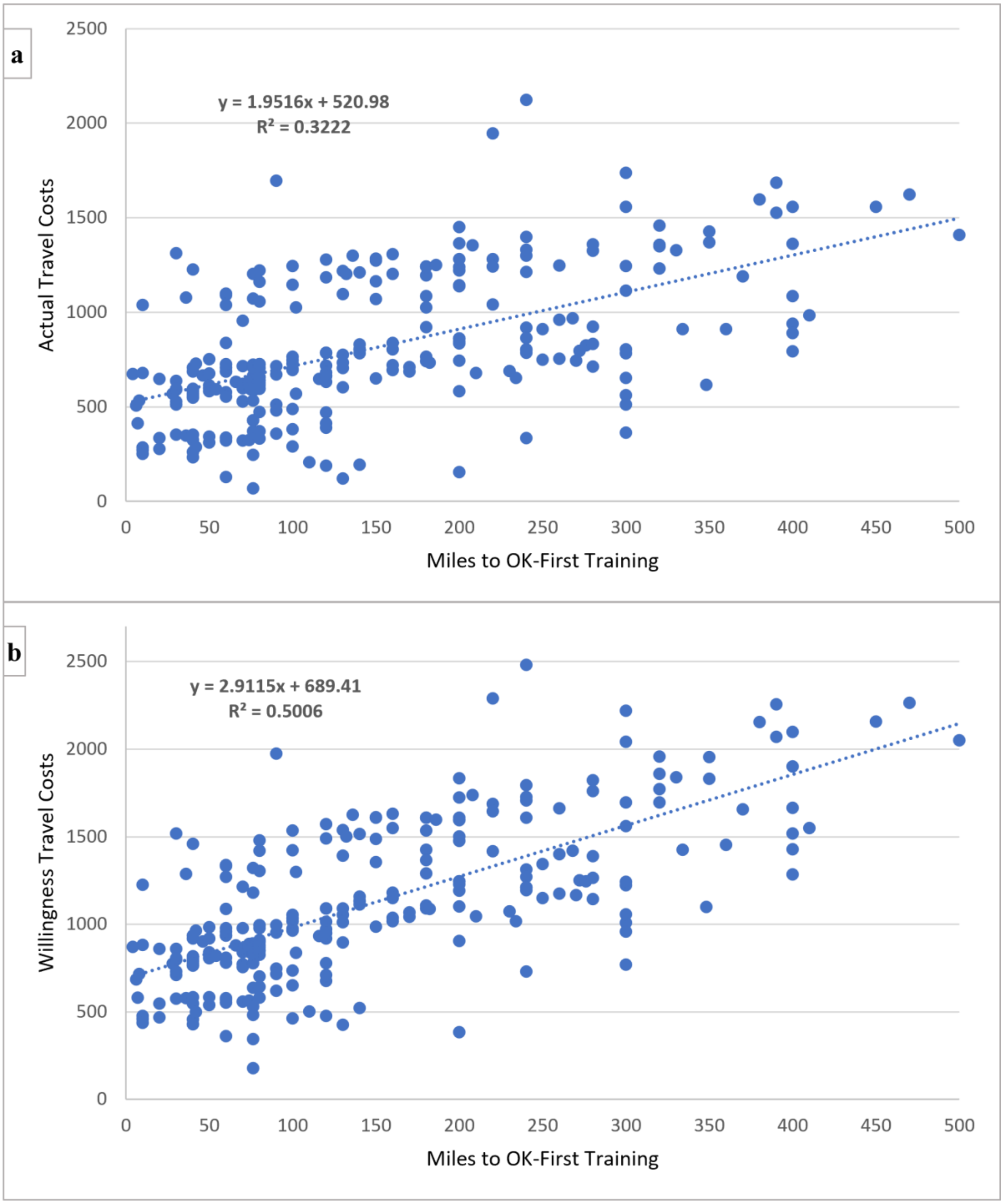

Figure 3-3: (a). Relationship between miles traveled and Actual Travel Cost (TCA) (n = 257); (b). Relationship between miles traveled and Willingness Travel Cost (TCW) (n = 257)

3.4.2 *Consumer Surplus*

The collective consumer surplus of participants based on willingness to travel was $80,000 and an average of $311 per participant to access the OK-First training. The minimum difference for participants for TCA and TCW was $101, and the maximum was $646. Figure 3-4 illustrates the demand curves for n=257 sample of the calculated individual actual aggregate cost of travel and individual aggregate willingness to pay for travel.

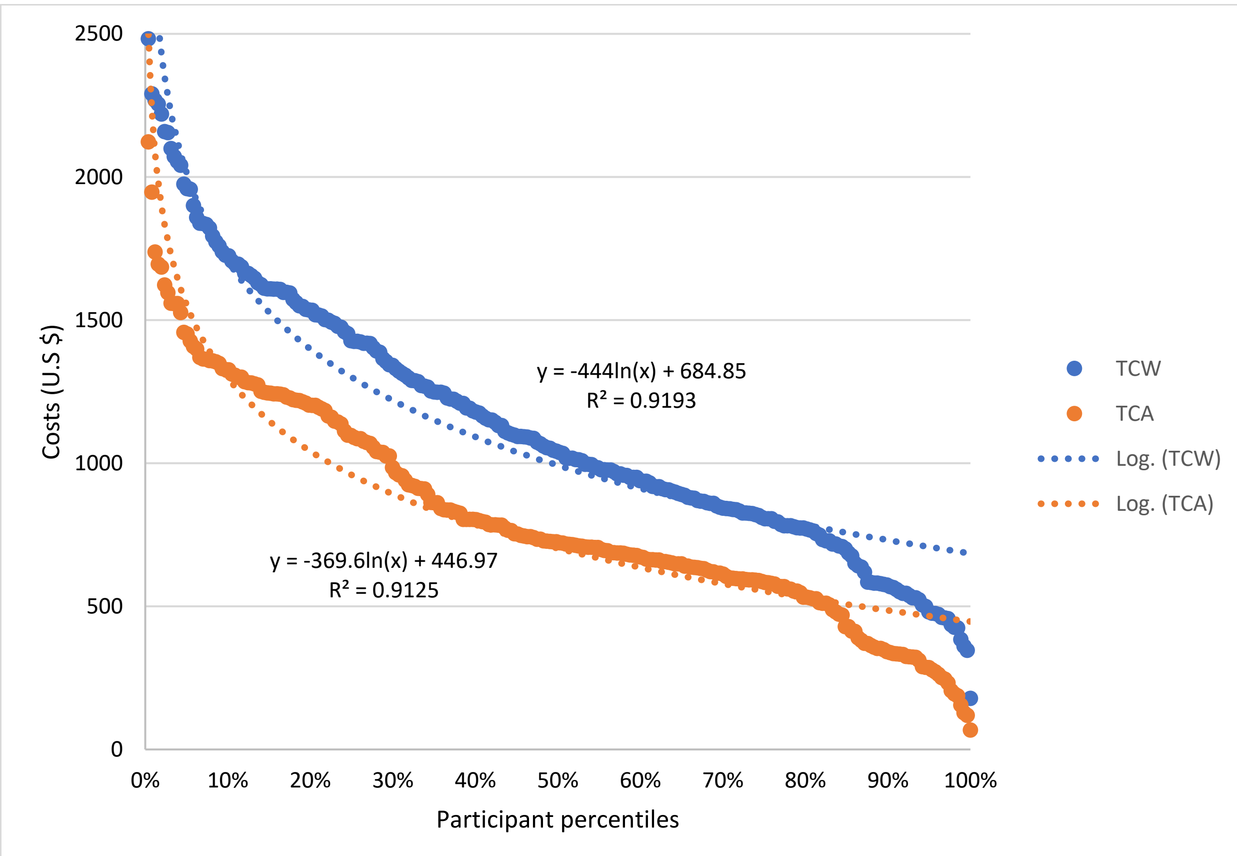

Figure 3-4: A set of demand curves for the n = 257 sample shows both the calculated individual actual aggregate cost of travel and individual aggregate willingness to pay for travel

Where TCW is the willingness travel cost and TCA is the actual travel cost calculated from participant survey.

The difference (i.e., $TCW - TCA = \int_0^1 (-444\ln(x) + 684.85)\,dx - \int_0^1 (-369.6\ln(x) + 446.97)\,dx$) between the individual aggregate willingness to pay and individual aggregate actual costs was estimated. Based on these curves, the difference was $ 312 per individual. Thus, the OK-First program provides an average surplus of $312 per participant.

Out of the n=257 participants, 100% stated a willingness to travel farther to access OK-First training. As illustrated in the demand curves, four distinct willingness to pay structures can be seen. The first group consisted of participants under the 20th percentile who paid over $1,200 to access OK-First training and were willing to pay over $1,700 in travel costs to attend OK-First training. Second, participants within the 15th and 35th percentiles paid slightly more than the average travel costs to access OK-First training and were also willing to pay marginally more to access this training. Participants with the 35th and 85th percentiles followed the demand curves. Participants between the 85th and 100th percentile paid less than the average and were willing to pay less to travel for OK-First training.

3.4.3 *Decision Tree analysis*

The estimated decision tree shows the significant values indicated by *p-values* in the nodes and yielded 6 clusters of Willingness Travel Cost (*WTC* - Figure 3-5). These decision clusters show that the modeled four factors interact to vary Willingness Travel Cost for OK-First participants. OK-First participants willing to spend the most had to travel 300 miles round trip to access OK-First (Node 11, Figure 3-5). The cluster with the maximum consisted of members who had either recently joined the program or those who had been in the program for over 20 years. Users willing to spend the 2nd highest amounts traveled intermediate distances (130-300 miles round trip) and intermediate numbers of past classes attended. Users who had attended fewer (1-5, 11-15) or many (>20) OK-First classes previously spent more in this intermediate distance category (Node 9, Figure 3-5) than those users who previously attended an intermediate number of previous classes (16-20 or 6 – 10 previous classes; Node 10).

Node 4 consisted of OK-First participants who had a minimum WTT of $179, a mean of $737, a median of $782, and a maximum of $1,271. This cluster of participants made weather-related decisions based on floods at least 1-5 times in the calendar year and reported cost savings of $5000 and below. The cluster also reported traveling less than 130 miles to OK-First training classes (Node 4, Figure 3-5). Participants who made decisions based on floods more than 6 times travelled less than 130 miles to access OK-First training. These participants had minimum WTT of $362, a mean of $899, a median of $899, and a maximum of $1,459 (Node 5, figure 3-5).

Node 6 consisted of OK-First participants who reported high-cost savings ($5,001 - $10,000 and over 10,000). These participants also traveled 130 miles or less to attend OK-First classes. Participants in Node 6 had a minimum WTT of $476, a mean of $1,086, a median of $986, and a maximum of $1,976.

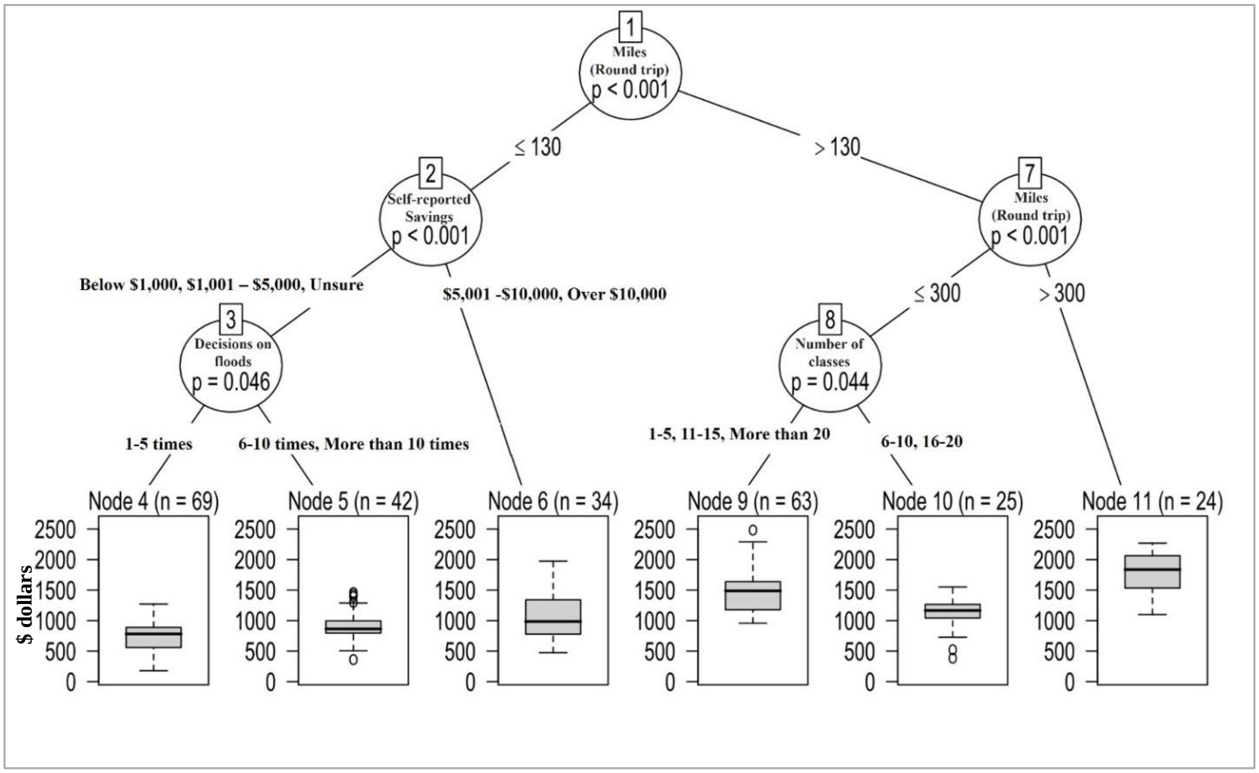

Figure 3-5: Decision tree illustrating the significant variables showing outcomes associated with OK-First users' willingness to pay for extra travel (n =257)

3.5 Discussion

The objective of this study was to use the principles of TCM to evaluate the economic value of the information provided by the OK-First training program; therefore, the monetary value of the OK-First program was quantified. The OK-First program in Oklahoma is valued at an estimated $254,000 per training for all OK-First users. This conservative estimate shows the economic value of programs like the OK-First for public safety. This survey sample for this research was truncated by design, it addresses the value of information provided to Oklahoma PSOs who participated in the OK-First program. This research does not address the breadth of value provided by this type of programming and education to individuals across occupations and disciplines. The TCM estimation is simply one piece of the puzzle in estimating and quantifying the benefits, services, and tools provided by the OK Mesonet. OK-First users estimated cost savings of using the OK-First at $1.2M per annum using OK-First Mesonet tools (Na-Yemeh et al. 2022). Ziolkowska (2018) used a combination of current market value and utility value methodologies to quantify the cumulative benefits for agricultural production from applying Mesonet weather information (comprising generated agricultural profits and prevented losses). The economic value of weather information provided by the Oklahoma Mesonet for agricultural production in the state was valued at $183.1M from 2006 – 2014 (Ziolkowska 2018). While Klockow et al. (2010) estimated total savings at $2.8–$5.4M, and an accumulative total of $4.4–$16.9M was estimated from 1996 to 2007 for farmers.

This study used modified TCM to evaluate the WTP to attend OK-First training. The analysis of paired individual p_i^a and p_i^w revealed a strong positive relationship between individuals' actual travel cost and the willingness to travel farther, indicating a willingness to pay more to access OK-First training. Despite this strong correlation, the WTP data is derived from a survey question, "*If you had to travel further for OK-First classes, how many more miles would you be willing to travel*?" which presents a hypothetical scenario that participants cannot be held accountable for fulfilling. Given this, it is difficult to determine whether they would be willing to travel farther in that scenario, a limitation of this approach. Furthermore, respondents may have been reimbursed for their travel costs, making them more likely to state a willingness to travel farther. Given that TCM accounts for the opportunity cost of time, the time to travel is not subject to reimbursement, indicating the value of the additional time participants are willing to allocate to travel and attendance of OK-First training. Despite these limitations, the participants' stated willingness to travel farther provides some insight into participant willingness to pay more for OK-First training.

The demand functions revealed that OK-First training had a choke price of approximately $2500. The choke price is the value where zero participants would be willing to pay to attend OK-First training. Thus, organizers could expect little interest in attending OK-First training if the costs climbed to that value. However, these demand curves may serve as planning tools for OK-First organizers and policymakers to estimate attendance based on changes in travel distance, implying a change in incurred costs to attend OK-First training. For example, based on these demand curves, a baseline cost to attend OK-First training of $1000 would retain the participation of approximately 50% of the first responders in the program.

Although TCM is seldom applied to valuing access to information, it has been applied to studies outside of the economic value of recreational sites, such as the management of protected natural areas. While these sites provide a wide range of benefits to communities, many consider areas with high visitation unsustainable, and managers of such facilities try to find alternative ways to address this issue. Font (2000) argued that the travel cost method helped measure the value of tourist behavior in favor of tourist activities. The Zonal TCM (ZTCM) was used to estimate the recreational benefits of a "site within a site" (Fleming and Cook 2008). The authors' estimates from the study confirmed a substantial current recreational value for both Fraser Island and Lake McKenzie. Therefore, caution was needed before restricting access to the publicly-owned recreational site. Torres-Ortega et al. (2018) described that ZTCM relates the number of trips from concentric zones surrounding a visitation site to analyze the correlation between the number of trips per population within a zone and the travel costs.

TCM has been applied to ecotourism and various types of education to offer a similar perspective to the approach of this study regarding the value of information. The environment as a good does not function as a commodity but as a service (Sander and Haight 2012). Researchers thus consider the environment as a "cultural ecosystem" during analysis. Hutcheson et al. (2018) used this principle to estimate the Hudson River Park's environmental education programs' economic value. The authors' estimate of the Park's annual education program benefits ranged between $7500 and 25,500, implying an average capitalized value on the order of $0.6 million. Additionally, Legg (2020) estimated the average individual value of environmental education to be $210, with an individual WTP of $259. The study by Legg (2020), which similarly focused on educational events within Oklahoma, showed that 358 individuals at 25 events valued environmental education at $75,285, with a collective WTP of $92,559.

This study did not produce an econometric model as in the traditional application of TCM. Instead, decision tree analysis revealed predictor variables associated with a more significant willingness to travel further or pay beyond dollar amount for OK-First training included round-trip mileage travel distance, self-reported savings, decisions based on flooding, and the number of OK-First classes participants had attended. Based on the geography of the state, it can be inferred that those who traveled the farthest were amongst the 25% of Oklahomans from rural communities (USDA-ERS). It was expected that those willing to pay the most for OK-First training had already traveled >300 miles. This may be due to the importance of self-sufficiency for rural emergency managers and the need for high-quality access to information for disaster preparedness. For example, a survey of 1,801 rural emergency medical services (EMS) showed that an event with <10 victims could overwhelm their EMS organizations and that their highest disaster preparedness priorities were on basic staff training (Furbee et al. 2006). Rural communities depend on emergency managers' ability to efficiently prepare and react to weather emergencies, which is supported by continuing education such as OK-First training.

Even though this study provided a monetary value of OK-First training and revealed associated predictors for a WTP beyond the dollar amount for OK-First training, there is still a need for further studies on the subject. This study used the individual approach to TCM (ITCM). In order to reveal more about the visitation rates from geographic zones across the state, zonal TCM should be applied to estimate the demand for training in different geographic regions of Oklahoma. Furthermore, understanding the reliance of the less-populated rural areas of the state on access to high-quality information for disaster preparedness may justify continued support of free educational programs such as OK-First.

Evaluating weather decision programs and weather information is a complex undertaking. It is crucial to incorporate different approaches to estimate the value these programs and information provide. Thus, other methods outside of TCM are necessary to quantify the use value of weather information, because this information is marketable to a select audience or individuals living within the boundaries of a particular jurisdiction. To comprehensively quantify the total value, impacts, and benefits of the OK-First program, future research will involve incorporating use and non-use valuation techniques. Incorporating use and non-use valuation ensures an assessment of the value of the OK-First program from different perspectives in terms of decisions made, lives saved, resources used and other socio-economic impacts of the program.

3.6 Conclusion

Information derived from free education is a public good that presents the characteristics of nonrivalry and nonexcludability. Therefore, valuing this information is difficult because it is generally intangible and difficult to express in measurable/quantitative (e.g., monetary) units. Given that there's no market for these types of goods, revealed preference methods or stated preference methods could be used to estimate its economic value.

This research used the modified TCM approach to value information provided by the OK-First program of the OK Mesonet. The modified TCM has multiple applications that have allowed for research outside of traditional applications such as evaluating the value of environmental education. While several studies have been conducted on the benefits of recreational sites and environmental education to both society and the environment, there are limited studies on the economic value of weather training. This study addresses this gap by providing a stated value of Mesonet-generated information to the users of the OK-First program based on travel costs.

Results show that the average individual value of OK-First training was $312. The total willingness travel costs for all participants were $288,000, with a collective surplus of $80,000. The OK-First program is valued at an estimated $254,000 per training for all participants. While one of the few studies that have utilized TCM to value a cultural ecosystem service, this conservative estimate suggests the importance of programs such as the OK-First training, especially for public safety officials in Oklahoma. The results of the study can be used for planning purposes for other states or institutions that want to evaluate the benefits of their program or provide funding to promote attendance.

3.7 References

Anderson, D. M., 2010: Estimating the economic value of ice climbing in Hyalite Canyon: An application of travel cost count data models that account for excess zeros. J. Environ. Manage., 91, 1012–1020, https://doi.org/10.1016/j.jenvman.2009.12.010.

Baumgart, L. A., E. J. Bass, B. Philips, and K. Kloesel, 2008: Emergency management decision making during severe weather. Weather Forecast., 23, 1268–1279, https://doi.org/10.1175/2008WAF2007092.1.

Boyle, K. J., 2003: Introduction to Revealed Preference Methods. A Primer on Nonmarket Valuation. The Economics of Non-Market Goods and Resources, P.A. Champ, K.J. Boyle, and T.C. Brown, Eds., Springer.

Brock, F. V., and P. K. Govind, 1977: Portable Automated Mesonet in Operation. J. Appl. Meteorol., 16, 299–310, https://doi.org/10.1175/1520-0450(1977)016<0299:pamio>2.0.co;2.

Brock, F. V., G. H. Saum, and S. R. Semmer, 1986: Portable Automated Mesonet II. J. Atmos. Ocean. Technol., 3, 573–582, https://doi.org/10.1175/1520-0426(1986)003<0573:pami>2.0.co;2.

Carlson, J. D., and T. G. Bidwell, 2008: OK-FIRE: A new weather-based decision support system for wildland fire managers. Oklahoma State University Cooperative Extension Service Rep. L-326p.

Chen, W., H. Hong, Y. Liu, L. Zhang, X. Hou, and M. Raymond, 2004: Recreation demand and economic value: An application of travel cost method for Xiamen Island. China Econ. Rev., 15, 398–406, https://doi.org/10.1016/j.chieco.2003.11.001.

Coupal, R. H., C. Bastian, J. May, and D. T. Taylor, 1999: The Economic Benefits of Snowmobiling to Wyoming Residents: A Travel Cost Approach with Market Segmentation. J. Leis. Res., 33, 492–510.

Crawford, K. C., D. A. Morris, R. A. Mcpherson, H. L. Johnson, M. A. Shafer, J. M. Wolfinbarger, and T. W. Hughes, 1998: OK- FIRST: A decision-support system for public-safety agencies. Preprints, 14th Int. Conf. on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrol- ogy, Phoenix, AZ, Amer. Meteor. Soc., 5–9.

De'ath, G., and K. E. Fabricius, 2000: Classification and regression trees: A powerful yet simple technique for ecological data analysis. Ecology, 81, 3178–3192.

EPA, 2020: What is environmental education? https://www.epa.gov/education/what-environmental-education.

Fiebrich, C. A., 2009: History of surface weather observations in the United States. Earth-Science Rev., 93, 77–84, https://doi.org/10.1016/j.earscirev.2009.01.001.

——, D. L. Grimsley, R. A. McPherson, K. A. Kesler, and G. R. Essenberg, 2006: The value of routine site visits in managing and maintaining quality data from the Oklahoma Mesonet. J. Atmos. Ocean. Technol., 23, 406–416, https://doi.org/10.1175/JTECH1852.1.

Fleming, C. M., and A. Cook, 2008: The recreational value of Lake McKenzie, Fraser Island: An application of the travel cost method. Tour. Manag., 29, 1197–1205, https://doi.org/10.1016/j.tourman.2008.02.022.

Font, A. R., 2000: Mass Tourism and the Demand for Protected Natural Areas: A Travel Cost Approach. J. Environ. Econ. Manage., 39, 97–116, https://doi.org/10.1006/jeem.1999.1094.

Furbee, P. M., and Coauthors, 2006: Realities of Rural Emergency Medical Services Disaster Preparedness. Prehosp. Disaster Med., 21, 64–70, https://doi.org/10.1017/S1049023X0000337X.

Golden, J. H., and C. R. Adams, 2000: The tornado problem: Forecast, warning, and response. Nat. Hazards Rev., 1, 107–118, https://doi.org/10.1061/(ASCE)1527 -6988(2000)1:2(107).

Harold, H., 1936: The General Welfare in Relation to Problems of Taxation and of Railway and Utility Rates. Econometrica, 6, 242–269.

Hocker, J. E., A. D. Melvin, K. A. Kloesel, C. A. Fiebrich, R. W. Hill, R. D. Smith, and S. F. Piltz, 2018: The evolution and impact of a meteorological outreach program for public safety officials : An update on the Oklahoma mesonet's ok-first program. Bull. Am. Meteorol. Soc., 99, 2009–2024, https://doi.org/10.1175/BAMS-D-17-0100.1.

Hoss, F., and P. Fischbeck, 2016: Increasing the value of uncertain weather and river forecasts for emergency managers. Bull. Am. Meteorol. Soc., 97, 85–97, https://doi.org/10.1175/BAMS-D-13-00275.1.

Hothorn, T., K. Hornik, W. Wien, and A. Zeileis, 2015: ctree: Conditional Inference Trees. 1–34.

Hutcheson, W., P. Hoagland, and D. Jin, 2018: Valuing environmental education as a cultural ecosystem service at Hudson River Park. Ecosyst. Serv., 31, 387–394, https://doi.org/10.1016/j.ecoser.2018.03.005.

Klockow, K. E., R. A. Mcpherson, and D. S. Sutter, 2010: On the economic nature of crop production decisions using the oklahoma mesonet. Weather. Clim. Soc., 2, 224–236, https://doi.org/10.1175/2010WCAS1034.1.

Lawson, M., 2019: Using Economics to Support Climate Adaptation. https://headwaterseconomics.org/equity/climate-change/economics-climate-adaptation/ (Accessed October 4, 2020).

Legg, T., 2020: Using the Travel Cost Method to value environmental education in the State of oklahoma. University of Oklahoma, 27–28, 33–36, 70 pp. https://shareok.org/handle/11244/324340.

Letson, D., D. S. Sutter, and J. K. Lazo, 2007: Economic Value of Hurricane Forecasts: An Overview and Research Needs. Nat. Hazards Rev., 8, 78–86, https://doi.org/10.1061/(ASCE)1527-6988(2007)8:3(78).

Mahmood, R., and Coauthors, 2017: MESONETS: Mesoscale weather and climate observations for the United States. Bull. Am. Meteorol. Soc., 98, 1349–1361, https://doi.org/10.1175/BAMS-D-15-00258.1.

McPherson, R. A., and Coauthors, 2007: Statewide monitoring of the mesoscale environment: A technical update on the Oklahoma Mesonet. J. Atmos. Ocean. Technol., 24, 301–321, https://doi.org/10.1175/JTECH1976.1.

Moody, D., and P. Walsh, 1999: Measuring The Value Of Information: An Asset Valuation Approach.

Morris, D. A., K. C. Crawford, K. A. Kloesel, and J. M. Wolfinbarger, 2001: OK-FIRST: A meteorological information system for public safety. Bull. Am. Meteorol. Soc., 82, 1911–

1923, https://doi.org/10.1175/1520-0477(2001)082<1911:OFAMIS>2.3.CO;2.

——, ——, ——, and G. Kitch, 2002: OK-FIRST: An example of successful collaboration between the meteorological and emergency response communities on 3 May 1999. Weather Forecast., 17, 567–576, https://doi.org/10.1175/1520-0434(2002)017<0567:OFAEOS>2.0.CO;2.

Morss, R. E., and F. M. Ralph, 2007: Use of Information by National Weather Service Forecasters and Emergency Managers during CALJET and PACJET-2001. Weather Forecast., 22, 539–555, https://doi.org/10.1175/WAF1001.1.

Na-Yemeh, D., R. Mahmood, G. Goodrich, K. Younger, K. Cary, and J. Durkee, 2020: Growing season air mass equivalent temperature (TE) in the east central USA. Climate, 8, 1–17, https://doi.org/10.3390/CLI8090095.

Na-Yemeh, D. Y., C. A. Fiebrich, J. E. Hocker, and M. A. Shafer, 2022: Assessing the Impacts of a Weather Decision Support System for Oklahoma Public Safety Officials. Weather. Clim. Soc., 1, https://doi.org/10.1175/WCAS-D-21-0086.1.

Oklahoma Mesonet, 2020: Benefits Overview. https://www.mesonet.org/index.php/site/about/benefits.

Parsons, G. ., 2003: A Primer on Nonmarket Valuation. C. et Al, Ed. 187–233 pp.

Riebsame, W. E., H. F. Diaz, T. Moses, and M. Price, 1986: The social burden of weather and climate hazards. Bull. Am. Meteorol. Soc., 67, 1378–1388, https://doi.org/10.1175/1520-0477(1986)067<1378:tsbowa>2.0.co;2.

Roff, D. A., and R. J. Roff, 2003: Of rats and Maoris: a novel method for the analysis of patterns of extinction in the New Zealand avifauna before European contact. Evol. Ecol. Res., 5, 759–779.

Rose, A., 2015: Macroeconomic consequences of terrorist attacks: Estimation for the analysis of policies and rules. Benefit-Cost Analyses for Security Policies: Does Increased Safety Have to Reduce Efficiency?, Edward Elgar Publishing Ltd., 172–200.

Sander, H. A., and R. G. Haight, 2012: Estimating the economic value of cultural ecosystem services in an urbanizing area using hedonic pricing. J. Environ. Manage., 113, 194–205, https://doi.org/10.1016/j.jenvman.2012.08.031.

Shafer, M. A., C. A. Fiebrich, D. S. Arndt, S. E. Fredrickson, and T. W. Hughes, 2000: Quality assurance procedures in the Oklahoma Mesonetwork. J. Atmos. Ocean. Technol., 17, 474–494, https://doi.org/10.1175/1520-0426(2000)017<0474:QAPITO>2.0.CO;2.

Stewart, T. R., R. A. Pielke, and R. Nath, 2003: Understanding user decision making and the value of improved precipitation forecasts. Am. Meteological Soc., 223–236, https://doi.org/10.1175/BAMS-85-2-223 In.

——, R. Pielke, and R. Nath, 2004: Understanding user decision making and value of improved precipitation forecasts: Lessons from a case study. http://sciencepolicy.colorado.edu/biblio/index.html. (Accessed September 29, 2020).

Torres-Ortega, S., R. Pérez-álvarez, P. Díaz-Simal, J. M. de Luis-Ruiz, and F. Piña-García, 2018: Economic valuation of cultural heritage: Application of travel cost method to the national museum and Research Center of Altamira. Sustain., 10, https://doi.org/10.3390/su10072550.

Tourkolias, C., T. Skiada, S. Mirasgedis, and D. Diakoulaki, 2015: Application of the travel cost method for the valuation of the Poseidon temple in Sounio, Greece. J. Cult. Herit., 16, 567–574, https://doi.org/10.1016/j.culher.2014.09.011.

Tucker, D. F., 1997: Surface Mesonets of the Western United States. Bull. Am. Meteorol. Soc., 78, 1485–1495.

US Bureau of Labor Statistics, 2020: Occupational Employment and Wage Statistics. https://www.bls.gov/oes/2020/may/oes_ok.htm.

USDA-ERS, USDA Economic Research Service: State Fact Sheets. https://data.ers.usda.gov/reports.aspx?StateFIPS=40&StateName=Oklahoma&ID=17854 (Accessed November 12, 2021).

Weaver, J., L. C. Harkabus, J. Braun, S. Miller, R. Cox, J. Griffith, and R. J. Mazur, 2014: An overview of a demographic study of united states emergency managers. Bull. Am. Meteorol. Soc., 95, 199–203, https://doi.org/10.1175/BAMS-D-12-00183.1.

Ziolkowska, J. R., 2018: Economic value of environmental and weather information for agricultural decisions – A case study for Oklahoma Mesonet. Agric. Ecosyst. Environ., 265, 503–512, https://doi.org/10.1016/j.agee.2018.07.008.

Ziolkowska, J. R., and Coauthors, 2017: Benefits and beneficiaries of the Oklahoma mesonet: A multisectoral ripple effect analysis. Weather. Clim. Soc., 9, 499–519, https://doi.org/10.1175/WCAS-D-16-0139.1.

Chapter 4: Impacts of Extreme Weather on Military Installations on Military Installations

Abstract

Oklahoma is home to five main military installations (Altus AFB, Fort Sill, McAlester Army Ammunition Plant, Tinker AFB, and Vance AFB). Not only are these installations vital to the United States, but they are significant drivers of Oklahoma's economic development. In 2010, military installations alone added $9.6 billion to Oklahoma's economy, representing more than 7% of its GDP. Oklahoma is prone to hazardous weather such as severe storms, tornadoes, hail, straight-line winds, and flooding. Extreme events tend to be disruptive to the operations of Oklahoma's military installations. These events negatively impact the economic potential for these installations, especially when they lead to base closures, delays in training, and deployment during disasters. This chapter analyzes weather events between 2015 and 2019 to assess the impacts of extreme events on these installations. Interviews revealed that weather-related decisions at installations are unit-specific and based on the type of events. Winter weather, floods, fire weather, severe thunderstorms, lightning, and excessive heat caused the most disruption to installations in Oklahoma. The impacts of these events ranged from delays or cancellations of training activities to closure of installations to non-essential staff. This study highlights the importance of early warning and forecasts for the Department of Defense for planning and the need for collaboration to mitigate the effects of extreme weather events and climate change.

Keywords: Decision making, Extreme weather events, Military installations, Oklahoma, Weather impacts, Weather monitoring,

4.1 Background

Military installations present a special-use instance of emergency management skills, data, and decision-making. This chapter investigates how emergency managers and others with operational weather safety responsibilities on military installations in Oklahoma approach their jobs. The chapter focuses on comparing the sources of data consulted, decision-making authorities and processes, and the broader context of preparing military installations for the effects of hazardous weather and climate change. In some cases, forecasters and emergency managers at military installations are required to consult specific sources of information. Therefore, they may operate under more constraints than their civilian counterparts (e.g., Garfin et al. 2021). Emergency managers on military installations also often have a narrower scope of responsibilities as compared to their civilian counterparts, who must consider impacts on a larger segment of society and the general public.

Another focus of this chapter is to investigate whether priorities expressed by the Department of Defense concerning readiness for climate change are reflected in the decisions made by emergency managers at military installations in an inland location such as Oklahoma (e.g., Garfin et al. (2021)). Coastal installations have begun preparing for the impacts of sea-level rise, but less attention has perhaps been given to inland installations (Scott and Khan 2016; Chadwick et al. 2011; Ratcliff and Smith 2011; Smith et al. 2010). However, one must also recognize that climate change is resulting in more extreme weather that affects inland installations, including flooding, extreme heat, the remnants of hurricanes, wildfire, and potentially changes in severe weather patterns (Garfin et al. 2021, 2017; Moss et al. 2017; Scott and Khan 2016).

In an effort to assess the impacts of extreme weather on military installations, this study seeks to answer the following research questions:

1. What are key weather variables for installations, and how are they used?

2. What are the impacts of extreme weather on installations?

3. How do installations prepare for extreme weather?

4.2 Potential threats to daily operations

The US Department of Defense (DoD) relies on military installations with extensive supporting infrastructure to prepare for and execute missions in support of US national security interests (Moss et al. 2017). However, the DoD faces emerging climate risks and challenges across its portfolio of responsibilities because many of these installations and their supporting infrastructure systems are located in areas prone to natural hazards (Garfin et al. 2017; Moss et al. 2017). Relevant exposures include the effects of extreme weather and climate such as floods, coastal storm surges, droughts, extreme temperatures, fires, winds, and other hazards (Moss et al. 2017; Scott and Khan 2016; Weatherly et al. 1992). These extreme weather events affect the day-to-day operations of the DoD in its core mission to protect global security through operation of hundreds of installations and as a significant land manager (Garfin et al. 2017; Smith et al. 2010).

Over the past few years, weather disasters have been incredibly destructive (Smith 2019, 2020). According to Smith (2020), historic 2019 U.S. inland flooding across many Central states followed the landmark 2018 and 2017 Atlantic hurricane and Western wildfire seasons, which set new damage cost records. Offutt Air Force Base in Nebraska, for example, was severely flooded (Missouri River flooding in March 2019). This resulted in damages of $10.8 billion and three deaths. This also happened to be the third U.S. military base damaged by a billion-dollar disaster event over six months (September 2018 – March 2019; Smith 2019). The other two installations were the Tyndall Air Force Base in Florida, which suffered $5 billion in damages from Hurricane

Michael (October 10-11, 2018), and the U.S. Marine Base Camp Lejeune in North Carolina which suffered extensive damage from Hurricane Florence (September 13 – 16, 2018). The estimated cost of rebuilding from just these three events totaled about $ 10 billion (YCC Team 2021).

According to Garfin et al. (2017), as both current climate variability and future climate change become issues of concern, there is a certain degree of uncertainty about the timing, pace, and severity of possible impacts, as well as options for managing and avoiding them. The DoD must use specific guidance on methods, best practices, and support services to establish adaptation and climate time-scale thinking as part of standard operating and facility management procedures (Garfin et al. 2017). Garfin et al (2017) believe that those best practices require a systematic approach that includes direct and continued engagement of installation personnel with researchers to: a) identify current climate-related issues of concern, and b) connect these concerns through cause-and-effect impact chains to amplified or attenuated future climate-related risks (Garfin et al. 2017).

Weatherly et al. (1992) classified the effects of extreme climate events on military operations into three categories: tactical, operational, and strategic. At the tactical level, the climate and its extremes affect personnel and unit issues and DOTMLPF (doctrine, organization, training, material, leaders, personnel, and facilities (Weatherly et al. 1992). At the operational level, severe weather may cause delays and disruptions in plans for mobility, lines of communication, points of embarkation, logistics, and support (Weatherly et al. 1992). At the strategic level, climate and extreme weather affect the national (and international) resources employed in addressing our national security objectives (Weatherly et al. 1992). An increase in these rapid events also means that more demand will likely be placed on the military for activities beyond war, particularly humanitarian responses to natural disasters (Scott and Khan 2016; Busby 2008).

4.3 Oklahoma Military Installations

The Department of Defense has a mission to provide the military forces needed to deter war and to protect the security of the United States (Chiappe 2011). As such, military forces rely on various installations for the infrastructure they provide for training needs associated with the preparation and execution of missions to defend security interests (Moss et al. 2017). The nation's military readiness and effectiveness are also ensured by the military installations that manufacture, maintain, and repair the military material to supply warfighters (Chiappe 2011). Oklahoma is home to five federal military installations (Altus Air Force Base (AFB), Fort Sill Fires Center of Excellence, McAlester Army Ammunition Plant, Tinker AFB, and Vance AFB). The five installations are the largest and have substantial economic impacts on the State, employing Oklahomans and those from across the United States (Chiappe 2011). These installations are vital to the preparedness of the nation's military forces and the security of the United States (Boone et al. 2019; Chiappe 2011).

Altus AFB has been the cornerstone of southwestern Oklahoma for 75 years. Altus AFB trains pilots in larger, multi-engine aircraft such as the C-17 and KC-135 (Chiappe 2011) and has sustained an average of 150 personnel a year deployed at any one time (Altus AFB 2019). Moreover, the 97th Operations Support Squadron Weather Flight team operates from Altus AFB (Boone et al. 2019).

Located in southwestern Oklahoma, the Fort Sill Fires Center of Excellence (FCOE) is the oldest military installation in Oklahoma. Fort Sill has been the home of Artillery since 1911 (FCOE 2019). Fort Sill provides basic combat training for Soldiers and Marines in Field Artillery and Air Defense Artillery occupations (Chiappe 2011).

The McAlester Army Ammunition Plant (MCAAP), located in southeast Oklahoma, supports conventional munitions, missiles, and logistics around the globe (Boone et al. 2019). In addition to this, MCAAP also renovates explosives and ammunition and demilitarizes equipment and explosives for the US Department of Defense (MCAAP 2019; Chiappe 2011).

Tinker Air Force Base (Tinker AFB) is a major military installation located in central Oklahoma (Tinker Air Force Base 2017; Chiappe 2011). The facility provides depot maintenance to aircraft in the USAF, the Air Force Reserve, the Air National Guard, the Navy, and foreign allied militaries (Chiappe 2011). Tinker AFB also maintains, repairs, and overhauls military aircraft and provides strategic capabilities to the military (Chiappe 2011), including flying AWACS missions.

Vance AFB is the Northernmost Specialized Undergraduate Pilot Training Base in Education and Training Command (Boone et al. 2019; Vance Air Force Base 2017; Chiappe 2011). The wing flew 46,546 sorties totaling 67,663 flying hours in the T-1A, Jayhawk, T-6A Texan II and T-38 Talon and graduated 294 pilots in fiscal year 2016 with no class "A" mishaps.

Considered as single-site establishments, these military installations are amongst the largest employers in the State. Combined, they have a tremendous impact on Oklahoma's economy (Chiappe 2011). In 2010 military installations alone added $9.6 billion to Oklahoma's economy, representing more than 7% of the State's GDP. The majority of this came from Tinker AFB and Fort Sill, which contributed $4.4 billion and $4.1 billion to the State's economy, respectively (Chiappe 2011).

In September of 2018, the Southern Climate Impacts Planning Program (SCIPP), a NOAA RISA team, and the Colleges of Atmospheric and Geographic Sciences and Engineering at the

University of Oklahoma hosted a workshop on *Weather and Climate Impacts on Military Operations*. The workshop focused on learning about the missions and operations of military installations and how weather and climate events impacted their services (Boone et al. 2019). The workshop had representatives from the five military installations and the National Guard, and members of the weather and climate research community across the University of Oklahoma. Results from discussions helped to identify potential threats to the daily operations of these military establishments and installations. This was important because any time these installations closed, not only did this cause operational and efficiency loss to the DoD, but there was a resultant economic loss for the State (Boone et al. 2019; Moss et al. 2017).

Vance AFB identified hail, icing, and tailwinds as having the most significant potential to be harmful to training planes (Boone et al. 2019). Participants felt that a two- hour lead time, when possible, would be enough in order to move their aircraft and issue warnings to their pilots. For Tinker AFB, heat conditions and extreme rainfall were the biggest threat to daily operations (Boone et al. 2019). The National Guard listed drought as a hazard that affected day-to-day operations (Boone et al. 2019). For MCAAP, the most significant economic impact from weather events was lightning. For all the installations, wildfires, floods, tornadoes, winter weather, hail, and heat caused disruptions to daily operations.

Participants also explained that these losses often resulted from a lack of expertise to plan adequately for events. For instance, Tinker AFB has in the past closed base operations due to predicted winter weather, although on several occasions conditions were not as adverse as predicted (Boone et al. 2019). Situations like this can be disruptive and expensive, especially when they involve transporting large equipment, aircraft, or deploying military members (Weatherly et al. 1992). Garfin et al. (2017) believe that expressing climate risks in terms of loss and damage-related costs highlights an opportunity to improve economic loss and damage data collection and report for military operations.

4.4 Extreme Weather Events in Oklahoma

Oklahoma is located in the Southern Great Plains. Humidity, cloudiness, and precipitation are higher than in the western and northern regions. Summers are long and quite hot, and winters are shorter and less rigorous than the Northern Plains states. The terrain is mostly plains, which vary from nearly flat in the west to rolling in the central and east.

Extreme weather such as heatwaves, droughts, tornadoes, and hurricanes have affected the United States since time immemorial (NCEI 2020). These events can be unexpected, severe, unusual, or unseasonal (NCEI 2020). Extreme weather often has significant economic impacts whenever they are experienced. According to the National Centers for Environmental Information, the US has sustained 254 weather and climate disasters between 1980 and 2019, in which the overall damages/costs of each of these disasters reached or exceeded $1 billion. The total cost of the 254 events exceeds $1.7 trillion (NCEI 2020). 2019 was also the fifth consecutive year (2015-2019), where more than ten billion-dollar weather and climate events impacted the United States (NCEI 2020). Within the last five years (2017 – 2021) there have been 86 billion-dollar disasters, resulting in the death of 4,519 people and with losses exceeding $700B in the United States. In effect, disasters are inevitable, expensive, and often affect lives and property (private and public).

Extreme weather conditions are a common occurrence in Oklahoma. Additionally, there has been a focus on understanding and improving emergency management during high weather-impacted situations using programs such as the OK-First and weather and climate workshops (Na-Yemeh et al. 2022; Hocker et al. 2018). Records from the Federal Emergency Management

Association (FEMA) presidential declarations (1953 – 2022) indicate that Oklahoma is ranked number 2 in disaster declarations categorized as severe storms and severe ice storms (FEMA 2022). On May 3, 1999, alone, 58 tornadoes occurred in Oklahoma, leaving 45 people dead and 600 injured (Brown et al. 2002). The tornado outbreak resulted in over $1.7B in damages and costs across Oklahoma-Kansas (Ross and Lott 2003). More recently, in 2021, Oklahoma was hit with 63 tornadoes (NWS 2022a).

An analysis of Storm reports from 2015 – 2019 confirms the perceptions of risks reported during the workshop. The data of NOAA's Storm Events Database shows that thunderstorm wind, hail, flash flood, flood, droughts, and tornadoes made up 89% of the 21 weather event types recorded in the State of Oklahoma between 2015 and 2019. The highest occurring events were thunderstorm wind with 30%, hail with 27%, and flash flood with 12%. Of the 77 counties in Oklahoma, Tulsa, Oklahoma, Comanche, Cleveland, Le Flore, and Texas reported the highest number of weather events reports. Together, these six counties represented 18% of the total number of weather events reported for all counties in the State. The annual distribution of events was fairly uniform, with the most events reported in 2015 and the fewest in 2016 (Figure 4-1).

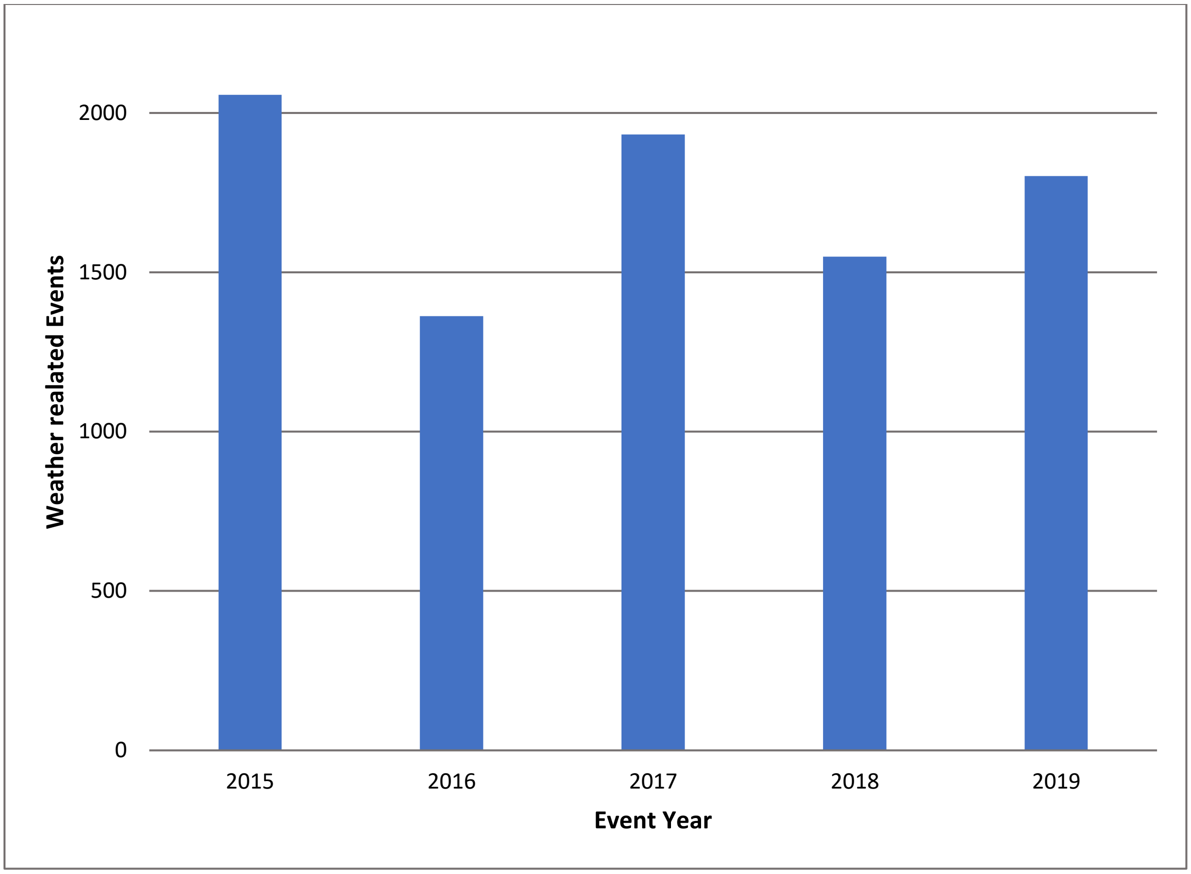

Figure 4-1: Weather-related events in Oklahoma from January 2015 to 2019

Figure 4-2 shows the spatial distribution of weather events reported in the NOAA's Storm

Events database in relation to the military bases. Tinker AFB (T-AFB) is located in an area of local maxima in central OK. Fort Sill Fires Center of Excellence (S-FCOE) is also located in a county with over 200 reported weather events. Altus AFB (A-AFB), McAlester Army Ammunition Plant (MCAAP), and Vance AFB (V-AFB) were all located in counties that reported weather events. Oklahoma and Tulsa counties, which are hotspots, are more populous areas and are likely biased in total number of reports due to population density. Nonetheless, this shows that all locations of military installations in Oklahoma have had to contend with numerous severe weather events over the five-year period.

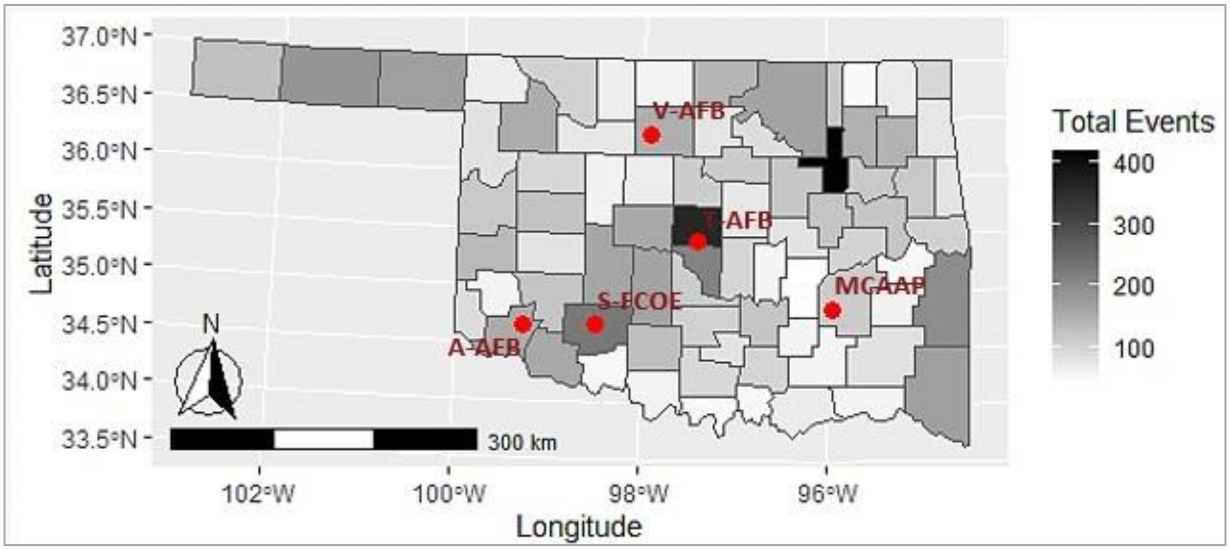

Figure 4-2: Total events by county from January 2015 to December 2019

NOAA's Storm Events Database analysis shows that heat, excessive heat, tornadoes, and thunderstorm wind had the highest reports of deaths and injuries in Oklahoma. When all counties that reported at least one injury from a weather event were analyzed, thunderstorms, heat, thunderstorm winds, extreme heat, and wildfires reported the most injuries for the five years under consideration.

The highest number of fatalities reported was associated with tornadic events. Wildfires, heat, and excessive heat also contributed significantly to mortality in Oklahoma. When considering both injuries and death, tornadoes alone injured or killed over 80 across the State, followed by excessive heat and heat, which accounted for 44 injuries or deaths over five years (Figure 4-3). Heat fatalities are often under-reported in databases such as Storm Events (Paul et al. 2018).

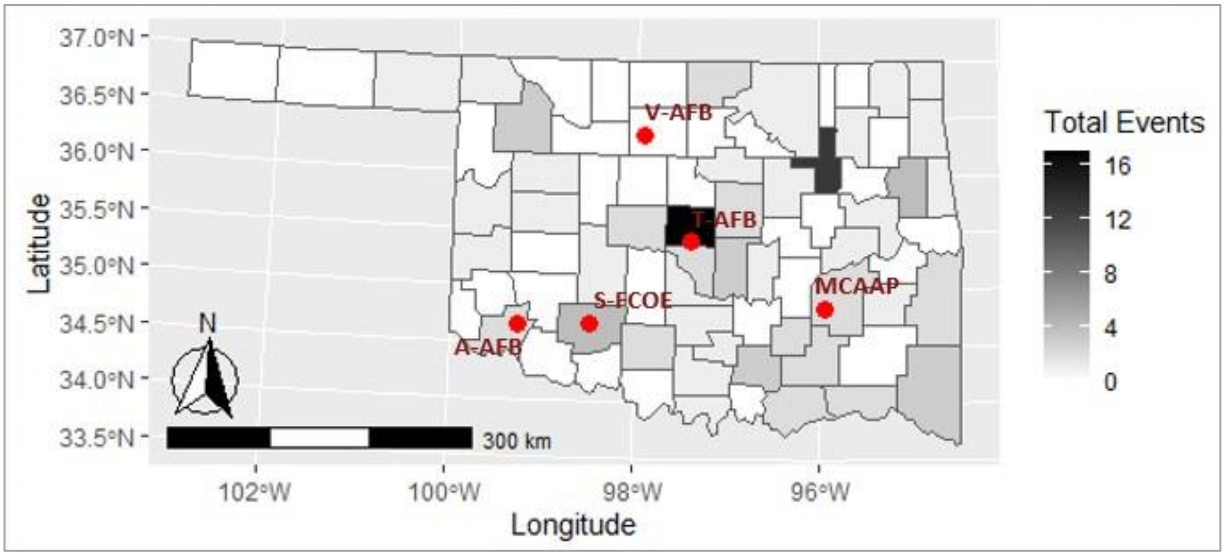

Figure 4-3: Total number of events with injuries or death by county from January 2015 to December 2019

Significant weather events that affected military installations in Oklahoma from January 2015 to December 2019 are summarized in Table 4-1. Weather variables and events were summarized using records from the Oklahoma Mesonet (www.mesonet.org), Global Historical Climate Network (GHCN), COCORAHS (www.cocorahs.org) and NOAA's Storm Events Database (https://www.ncdc.noaa.gov/stormevents/ftp.jsp). Drought data (i.e., events qualifying as severe, extreme or exceptional) were from the US Drought Monitor (https://droughtmonitor.unl.edu).

Table 4-1: Significant weather variables and event days for Oklahoma military installations

Event Type	**Description of weather variable or event**	**Altus AFB**	**Fort Sill**	**MCAAP**	**Tinker AFB**	**Vance AFB**
Temperature	Days above 100°F	58	48	10	9	32
Heat Index	Days above 110 °F	12	17	9	7	19
Wind speed	Days above 58mph	12	3	-	-	8

Event Type	Description of weather variable or event	Altus AFB	Fort Sill	MCAAP	Tinker AFB	Vance AFB
Rainfall	Days above 2 inches	11	11	32	19	10
Wind Chill	Days with values below 0 °F	12	29	8	16	28
Hail	Days with hail reports	51	75	22	94	44
Ice Storms	Days with ice storm reports	2	3	-	3	3
Snow Fall	Days with 1 inch or more	8	5	4	5	5
Drought	D2 - D4	4	4	2	3	3

4.4.1 *Excessive heat*

Extreme or excessive heat refers to summertime temperatures that are much hotter or more humid than the average (CDC 2019). According to the NWS's weather-related fatality and injury statistics (https://www.weather.gov/hazstat/), heat-related fatalities are the deadliest of all weather-related hazards. However, various factors (e.g., death doesn't occur immediately after heat exposure or happens from exposure to heat either as an underlying cause or contributing factor and therefore not recorded as heat-related) influence the ability of statistical approaches to estimate the actual number of deaths associated with extreme heat events (EPA 2022). The CDC estimates that at least 618 people in the United States are killed annually, on average, by extreme heat. Some statistical approaches estimate that more than 1,300 deaths per year in the United States are due to extreme heat, compared with 600 deaths per year in the "underlying and contributing causes" data set (EPA 2022). The 30-year average fatalities (1991-2020) for heat was 143 for the United States (NWS 2022b). An analysis of the Storm Events Database between January 2015 and December 2019 shows 264 excessive heat and heat events reported across Oklahoma (Storm Events Database 2022). These events resulted in four deaths and 528 injuries.

4.4.2 *Flash Floods and flooding*

In the United States, flash flooding is considered one of the deadliest weather-related hazards (Ashley and Ashley 2008). Floods, whether originating from heavy rain, snowmelt, structural failure, or a combination of factors, are the second deadliest (in comparison to heat) of all weather-related hazards in the United States (NWS 2022b). The 30-year average (1991-2020) of fatalities for floods was 85 and the 10-year average was 94 for the United States (NWS 2022b).

4.4.3 *Tornadoes*

According to Laferance (2015), although forecasts had improved since the 1980s when the vast majority of tornadoes had no warnings, improved forecasts in recent years have not always translated into actions taken by the public to prevent injuries and fatalities. For instance, officials put out a warning 16 minutes before the tornado that decimated Moore, Oklahoma, in 2013, formed and killed 24 people (Laferance 2015). Two years prior, sirens sounded 20 minutes before the disastrous tornado touched down in Joplin, Missouri and killed 158 people.

Between 2015 and 2019, there were 522 tornado reports in Oklahoma (Storm Events Database 2022). Of this number, 44 were EF2 or higher (NWS 2022a). These outbreaks resulted in nine deaths, 161 injuries and cost over $160M in property damage (SPC 2022; Storm Events Database 2022; The Oklahoman 2022).

4.4.4 *Drought and Wildfires*

Drought is a regular part of Oklahoma's climate, and episodes can last from a few months to several years. Seasonal droughts can occur at any time of the year. Between January 2015 and December 2019, there were 950 drought events reported across the State. Drought events such as these can last a few months and elevate wildfire danger, and impact municipal water use (Arndt

2005). As such, wildfires in Oklahoma are common occurrences, as well. Between 2015 and 2019, there were 168 wildfire events reported, these led to 11 injuries and four deaths within the time frame (Storm Events Database 2022). The Rhea fire alone in 2018 resulted in over $50M in damages (Ziolkowska 2019).

4.4.5 *Thunderstorms, lightning, winds, and hail*

Severe thunderstorms along with tornadoes, hail, and destructive winds cause an average of 5.4 billion dollars of damage each year across the United States (Gensini and Brooks 2018). According to the NWS weather-related fatality and injury statistics, the 30-year average (1991-2020) of fatalities for lightning was 39, and the 10-year average was 24 (NWS 2022b). Between January 2015 and December 2019, there were 12 lightning events reported in Oklahoma. These events resulted in one injury and over $1.2M in property damages (Storm Events Database 2022e). The 10-year average for wind fatalities in the US was 60 (NWS 2022b). There were 2597 reports of thunderstorm wind events and 20 injured reported between January 2015 and December 2019 (Storm Events Database 2022). Additionally, there were 184 reports of high winds across the state within the period. There were 2336 hail reports in Oklahoma between January 2015 and December 2019 (Storm Events Database 2022). Damaged property costs exceeded 2.5M for hail damage in Oklahoma. These damages are greater in neighborhoods that are hit with hail damages.

4.4.6 *Winter weather, Winter storms, and Ice storm*

Blizzard conditions often impede travel, and locations in northern Oklahoma especially can be buried under drifts of 5-10 feet of snow (Oklahoma Mesonet 2022). According to NOAA's State Climate Extremes Committee (SCEC), the coldest day ever recorded in Oklahoma was on February 10, 2011, in Nowata, with a low temperature of -35°C (-31°F) (NCEI 2022b). There were reports of snow up to 27 inches in localized areas of northeast Oklahoma. In Medford, Oklahoma, the lowest wind chill of -44°C (-47°F) was experienced on February 10, 2011 (Oklahoma Mesonet 2022).

The NWS classifies cold and winter fatalities as different categories. The 30-year average (1991-2020) for winter weather was 35 fatalities; for cold, the 30-year average (1991-2020) was 37 fatalities (NWS 2022b). The 10-year averages were 27 and 30 for winter and cold, respectively, in the United States. There were 98 winter weather events reported between January 2015 and December 2019 in Oklahoma (Storm Events Database 2022). Within the same period (2015-2019), for winter storms, 67 events were reported (Storm Events Database 2022). There were 82 Ice Storm events between 2015 and 2019. These events led to nine deaths, six injuries, and $93M in property damages (Storm Events Database 2022).

4.5 Interviews with Military Personnel

Follow-up interviews and focus groups from military installations were undertaken to explore the impact of extreme weather specific to military installations in Oklahoma. The period of analysis for the research was 2015-2019. Participating installations were given the option to do interviews or focus groups based on their availability; results discussed from these interviews and focus groups are from Fort Sill and Tinker AFB, which are the two largest installations in the state.

4.5.1 *Interview design and population*

An interview guide consisting of 14 semi-structured interview questions, a mix of primary and secondary questions, topic areas, and word questions (such as descriptive, storytelling, and opinion) was designed for the study. Tinker Air Force Base requested to see the questions before the focus group. Fort Sill Fires Center of Excellence did not ask to see the questions before hand.

For both interviews and focus groups, a combination of notetaking and audio recordings were used.

The interviews and focus groups were conducted following Institutional Review Board approval (#13284) on April 14, 2021. The recruitment document (see appendix) was sent to the installations through individuals who had participated in an OK-First (Oklahoma First Response Information System using Telecommunications) training, tabletop exercise, or workshop at the National Weather Center. Both installations had active OK-First members. The interviews and focus groups were conducted between July 31, 2021, and August 31, 2021. Two interviews were conducted for Fort Sill Center of Excellence and one focus group with personnel from the Tinker Air Force Base. Other military installations in Oklahoma did not respond to requests for interviews.

All participants agreed to be quoted directly and contacted for future research. The Range Officer at Fort Sill was interviewed. He was acting as the Training Division Chief at the time of the interview. The Range Officer ensures safe training and oversees all range aspects and training at Fort Sill with all the units. The Training Division Chief supervises the range, the Mission Training Center, and the Regional Training Support Center. The Emergency Manager (EM) for Fort Sill was also interviewed. The EM officer ensures that the installation is prepared for and responds to any disasters.

The focus group at Tinker Air Force consisted of three individuals: the Emergency Manager, the Weather Flight Chief, and the Wing Weather Officer. The Emergency Manager ensures that the installation was prepared for and ready to respond to any types of disasters that may affect the installation. The Weather Flight Chief is the full-weather advisor to the operational units at Tinker and the senior leadership. This individual provides leadership with the weather intel to make operational decisions, adjusting operations if needed. The Wing Weather Officer serves as a liaison between the weather flight units to ensure that weather support has adequate information to make weather-related decisions.

4.5.2 *Coding and analysis*

The topics of interest for the study included the sources of information used, the types of extreme events, decisions made, who made those decisions, and how installations prepared for these events. Hence, a small set of priori (or deductive) codes were initially used for the study. When coding began, a few inductive codes were added (see Appendix F). This made it possible to discern how reviewing the data added new insights from the predetermined topics. This resulted in 14 sub-themes which were grouped into four themes (see Tables 2-5) for results.

4.6 Results

4.6.1 *Sources of information*

Both military installations used a wide range of data sources to be weather-ready for extreme weather events (Table 4-2). However, civilian weather resources were supplementary except for the National Hurricane Center, the sole hurricane authority. As the Wing Weather Officer of Tinker pointed out, military installations do not have to follow the Storm Prediction Center (SPC) or the National Weather Service (NWS). These are all added-on tools. Fort Sill highlighted some weather variables and how they were necessary for their installation. Fort Sill made use of the wet-bulb globe temperature. This information was transmitted to all units on the field to follow heat cap level guidelines on the amount of rest required per hour. Additionally, lightning information within 30 nautical miles off Fort Sill is passed through the units for appropriate actions.

Since Southwest Oklahoma tends to be dry during the summertime, Fort Sill pays attention to weather conditions that might cause fires and affect ranges, training, and units on the field. Thus, data on wind, humidity, and drought information are also helpful. The Training Division Chief pointed out that meteorological data is critical for Fort Sill as a predominantly Artillery post. For example, the information is used to calculate fire solutions of some weapon systems. Also, as wind speeds and direction differ at different altitudes, ammunition acts differently under varying weather conditions. Overcast conditions, as well as barometric pressure levels, are equally as important. Barometric pressure is important for dispersion of the noise of the weapon systems. So, for example, if there is lower barometric pressure and overcast conditions, the sound close to the ground, which may cause some complaints off-post. According to the Training Division Chief, there's a whole arsenal of things with regards to weather that helps them make the right decisions.

Table 4-2: Sources of information

Installation	Primary Sources	Sources of information on and off-site	Other details
Fort Sill Fires Center of Excellence	- Weather Detachment at FCOE - Barksdale Air Force Base	- Wet-bulb Temperature - Lightning strikes - Wind readings - Overcast conditions - Barometric pressure - Mesonet Data (daily) - Local meteorologists and local news channel - National Weather Service - Storm Prediction Center	- Weather detachment at FCOE handles forecasts at certain times. - When they're not operational, forecasts come from Barksdale Air Force Base. They use a framework like the NWS.
Tinker Air Force Base	Air Force Products: - Deterministic Model - Satellite Ensemble Suites - Realtime Radar - National Hurricane Center (NHC)	- National Weather Service (Thunderstorm Charts) - Storm Prediction Center - Other civilian models	- Forecasts are derived solely from Air Force Weather Forecasters. - The only source Tinker remains consistent with is the NHC.

4.6.2 *Weather-related events and decision making*

Participants for the study emphasized that they had advisory roles regarding extreme events and decision-making. Weather-related decisions were made uniquely by each unit and the command decision at Fort Sill and by the installation Commander at Tinker Air Force Base. Table 4-3 shows the types of events participants perceived as the most disruptive to their installations. Floods were the most disruptive for Fort Sill, and winter weather and lightning caused the most problems for Tinker Air Force Base. Lead time depended on the event of the unit involved, and this information was provided by Air Force Weather. Table 4-3 also shows the generalized weather decisions that installations made in extreme weather situations. At Fort Sill, decisions based on heat are on categories (zero through a heat cap five level, with five being the hottest). Category five signifies that more rest and breaks were required while training. Antennas are taken down when lightning is detected or strikes occur within the five nautical mile radius.

Preparations for hazardous weather are usually in place on the operational side for Tinker Air Force Base and its mission to national security. These measures ensure that these critical missions are not severely hindered due to unforeseen weather events. The installation also makes decisions to ensure that passageways are clear and individuals on and off the base are safe or transported home promptly. These efforts include coordinating with outside agencies to relay messages on icy bridges and procuring sand and salt for roads. These generalized decisions give installations the chance to move promptly into recovery mode after an event so operations can run smoothly.

Table 4-3: Types of weather events, lead times, and generalized decisions

Installation	**Types of events**	**Generalized weather-based decisions**	**Lead time**
Fort Sill Fires Center of Excellence	- Winter weather (Ice storms, Snowstorms) - Floods - Fire weather	- 0-5 heat cap for rest - Adjusting aim points - Fire solution calculation - Precautionary measure for lightning - Closing installation - Curtailing services	- It depends on units in the field - Regulations provide timeframes for the installation from air force weather (e.g., it's usually a 15 minute plus lead time for tornadoes. For winter storms, it's the potential 12 to 24 hour timeframe)
Tinker Air Force Base	- Winter weather (Freezing rain, hail) - Severe thunderstorms - Tornadoes - General Thunderstorms - Excessive heat - Lightning	- Preparation to get materials (salt and sand) for roads - Take extra delivery of resources - Get people off or on Base - Coordinating with agencies - Operational preparations for missions to continue as normal as possible	- Multiple Watches, Warnings, and Advisories (WWA) are sent out depending on the event. - Usually, there is a one-hour lead time for most WWAs (e.g., once a WWA for severe thunderstorms, snow is issued, there is enough time to enact plans set out to mitigate the effects on aircraft).

4.6.3 *Impacts of extreme weather events*

Both Fort Sill and Tinker AFB emphasized how their installations were impacted between 2015 and 2019. Participants for the study noted that these impacts were too many to enumerate and could not discuss some disruptions or decisions made for security reasons. Table 4-4 summarizes some impacts, costs, and damages for selected events that could be addressed. There are roughly 80,000 people associated with Fort Sill (e.g., active duty, family members, retirees, or DoD beneficiaries). As such, Fort Sill puts over $2 billion into the community annually. Disruptions, delays, or closures to the installation mean all these people and the community are affected. Participants noted that since Lawton never closes for any weather event, people in the community could shift their purchases downtown instead of on the base.

Similarly, Tinker AFB emphasized the importance of early forecasts on mitigating the effects of extreme weather. "*On the operational side of the house, obviously Tinker has, some very important missions to our national security, and if we had not forecast that event obviously those missions would be severely hindered, had they not had those five days to plan in advance to ensure that their missions continued, as close to normal as possible."*

At Fort Sill, one participant reported that they had *probably* canceled up to 500 training events within the period. Events such as winter storms could cause delays in opening installation and floods resulted in delays or cancellation of training. Wildfires and lightning often resulted in rescheduling or canceling training events. Participants at Tinker AFB elaborated on the importance of aircraft to their mission. They explained that airplanes had specific sensitivities and events such as winds, lightning, or general thunderstorms that would affect tasks. Most times, these events resulted in delay or cancellation of flights: *"each one of those flights is a training mission for the United States Air Force when they take off out of Tinker. So, you know, whenever weather has to* *delay or cancel flights, it's a pretty big impact to the mission"* emphasizes how weather events can disrupt these missions. Participants could not disclose too much information on decisions made regarding hail when dealing with aircrafts. However, they stressed that each flying unit had its plans when there was hazardous weather and would implement the strategies based on forecasts. General impacts around the Base included cancellations of outdoor activities during lightning events.

Participants for Tinker AFB gave examples of extreme weather events that were costly to the installation. Three extraordinarily damaging and expensive events are wildfires, freezing temperatures, and floods. Freezing events can cause significant damage and result in frozen pipes. Fort Sill lost a 17-million-dollar bridge and over $27 million in damage from a recent flooding event resulting from the release of water from a dam during a major storm. There were also reports of heat injuries within the timeframe.

Table 4-4: Impacts of extreme weather events

Installation	Disruptions, impacts, and decisions	Savings and impacts	Costs and damages
Fort Sill Fires Center of Excellence	- Up to 500 training cancellations in 12months - Reschedule training due to flooding - Lighting prevents training - Snow and ice have led to disruptions - Weather warnings impact the ability to conduct training - Allocation and use of equipment - Delay opening installation - Close installation to non-essential personnel - Training areas inundated - Fighting fires in and out of the installation - Heat injuries	- Economically over $2 billion to the community - Roughly 80,000 are associated with the installation annually	- Major damage to bridges - Damages from frozen pipes - Inaccessible training sites - Loss of a $17 million bridge and over $27 million in damages from a recent flash flood
Tinker Air Force Base	- Winds, lightning, and thunderstorms affect airplanes - Damage to foliage and vegetation - Disruption of the electrical grid - Flights must be canceled or delayed - Implement work-rest cycles for excessive heat - Manage aircraft sensitivities due to weather - Units implement laid out plans - Manage lightning threats for outdoor activities	- Tinker has essential missions to national security, and early forecasts save costs and continuation of missions	

4.6.4 *Preparedness for extreme weather*

Both military installations run exercises, monitor forecasts, and have unit-specific plans for long and short-term management of extreme events. When interviewed about how researchers could assist in helping installations manage and plan for extreme conditions, participants from Fort Sill reported that improved flood forecasting would be beneficial because flooding was one of the more expensive weather events. Because both installations are required to use Air Force Weather resources, and other sources are used as supplementary resources, the collaboration point for future research for improved models and forecasts is the Air Force Weather Detachment at FCOE and the 557th Weather Wing Offutt Air Force Base, Nebraska. These details are summarized in Table 4-5. None of the installations spoke about climate change or its impacts on extreme events on their installations or any plans from the state or national level addressing how climate change affects their installations. This is relevant because the DoD launched a climate assessment tool to help combat climate change and prepare for extreme events at all DoD installations.

Table 4-5: Preparedness and Research Opportunities

Installation	Short term	Long term	Research opportunities	Climate Change
Fort Sill Fires Center of Excellence	- Running exercises focused on expected weather (e.g., heat for summer and snow for winter) - Procuring plows, sand, and salt to support training - Going through the *deliberate risk assessment worksheet* - Gathering and engaging crisis action team - Air Force Weather - Mesonet data - SPC - NWS	- Monitoring forecasts both long and short term - SCIPP information - Air Force Weather	- Better forecasting for ice storms and flooding - The primary weather source is the Air Force Weather Detachment at FCOE and Barksdale Air Force Base - Other sources are supplementary	NA

Installation	Short term	Long term	Research opportunities	Climate Change
Tinker Air Force Base	- Unit specific decisions based on WWA - Monitoring forecasts based on trends and models - Provisioning of information to leadership - Procuring sand and salt - Conducting quarterly training/seasonal training (e.g., in the winter, training is focused on springtime weather)	- Continuous training for long term preparations - Sending observations, WWA issued, climatology, etc. to the - Fourteenth Weather Squadron in Asheville - Weather briefing reports (at least 3-4 times a year to prepare the personnel on hazards)	- The main avenue for research is the Air Force Weather. - The installation doesn't dabble with experimental products. - The main weather wing is the 557th weather wing and the Offutt Air Force Base in Nebraska. - These two weather wings are the collaboration point for new products and models. The Air Force puts a lot of money into their products and works hard to improve them.	NA

4.7 Discussion

Military installations across the United Sates are crucial for national security. However, these installations can be in areas prone to hazards and thus result in damages, closures, or lack of efficiency, which all have economic impacts. A changing climate is also likely to affect critical military infrastructure. Sea level rise and changes in magnitude and frequency of extreme weather pose a risk to defense property such as naval and military bases (Acclimatise, UK, and UA SERDP Project RC-2232 Team, 2015). Training and workshops have been organized to help the military understand climate-related impacts to help minimize damages and costs. Garfin et al. (2017) studied the British and Australian militaries, the State of California, the ports of Los Angeles, Humboldt Bay and San Francisco Harbor, the Port Authority of New York & New Jersey, and the extractives sector, which have qualities like those of the DoD. These organizations have worked hard to integrate climate change and uncertainty with their planning and operational practices.

According to the Yale Climate Connections (YCC) Team, extreme weather events cost the military billions of dollars annually. This has brought a new sense of urgency to addressing climate change as a national and global security issue (YCC Team 2021). Military installations in Oklahoma are exposed to several extreme conditions, including floods, extreme heat, winter storms, tornadoes, and lightning, which all affect day-to-day operations and are expensive. Fortunately, severe weather has not always resulted in fatalities in the State, as illustrated using NOAA's Storm Events Database report. Previous research shows that Watches, Warnings and Advisories (WWAs) from sources such as the NWS and SPC have reduced the likelihood of fatalities, especially during tornadoes. As a result, over the last 50 years, increased warning lead times and improved public compliance to warnings have contributed to a decrease in deaths and injuries (Boruff et al. 2003).

Interviews revealed the effects of extreme weather on Fort Sill and Tinker AFB previously identified by Weatherly et al. (1992). At the tactical level, hazardous weather events influenced and affected training schedules, personnel deployment, and acquisition of materials. Severe weather also caused delays and disruptions to missions or closures of installations to the non-essential staff at the operational level. And finally, at the strategic level, climate and extreme weather affected resources employed in addressing national security objectives. For example, military personnel performed duties such as fighting wildfires on and off base. As such more demand was placed on the military far beyond war to respond to hazardous weather events (Scott and Khan 2016; Busby 2008; Weatherly et al. 1992)

Participants in this research also discussed how they dealt with severe weather routinely. These hazardous events are expensive and hinder missions. Specific details could not all be discussed in this study about the severity of the impacts and decisions that are made due to national security. John Conger, Director of the Center for Climate and Security, reported that "*increasingly, extreme weather is imposing a cost on DOD bases, not only in dollars but also in readiness. It is impacting missions and operations*" (YCC Team 2021). To this point, the Air Force invests money and resources in Air Force Weather, further illustrating the cost and impact of hazardous events. Another way the DoD can address issues primarily related to floods and tornadoes is to invest in infrastructure. Research shows that even though huge costs are associated with the purchase, installation, and maintenance of real-time data collection systems, reliable systems pay back their cost many times in hazard situations (Ziolkowska et al. 2017; Gruntfest and Handmer 1999). Past flood events have proved the usefulness of flood systems to prevent property damage, loss of lives and increase the efficiency of emergency operations. Because it is not feasible to move military installations from storm prone areas, there is a need to keep these strategic locations intact in the face of weather and climate threats.

The DoD in 2021 began a mission to assess climate risks at installations across the United States within 12 months. This was the first step in planning to prepare for and respond to more extreme storms, rising seas, heat waves, and droughts (YCC Team 2021; Olson 2021). In a news release, the Pentagon set a goal of completing similar assessments at all major installations outside the U.S. within two years. The Climate Assessment Tool was launched to evaluate risks to the roughly 5,000 Defense Department sites worldwide. The tool combines data from past extreme weather events, such as hurricanes and tornadoes, with projected future changes – for example, in sea level and average temperatures – to produce "hazard indicators," according to DoD (Olson 2021). Although the DoD reports a sense of urgency in addressing climate change to prepare for extreme weather, interviewees did not discuss this tool or an awareness of its inclusion in their long or short-term plans to prepare for severe weather. Indeed, directives from the Pentagon are a strong motivator; however, integrating climate-smart strategies into day-to-day practices and long-term planning processes by military and civilian employees at the installations will be needed to manage physical climate risks (Garfin et al. 2021).

As summarized by Garfin et al. 2021, the DoD still needs to *escalate climate risk management efforts in order to meet its mission and ensure the safety and security of its employees* *and facilities.* Addressing climate challenges is a complex undertaking, and it requires interdisciplinary approaches and collaboration with the DoD to accomplish this. Integrating top-down and bottom-up strategies, combined with the flexibility to partner and gain expertise from networks of researchers and stakeholders, will help navigate the complex terrain of DoD's new mission to adapt to climate change. The DoD in Oklahoma can partner with researchers at the University of Oklahoma and collaborate with affiliates such as the OK-First via training and tabletop exercise to prepare for and mitigate the impacts of extreme events.

4.8 Conclusion

Oklahoma is home to Altus AFB, Fort Sill Fires Center of Excellence, McAlester Army Ammunition Plant, Tinker AFB, and Vance AFB. These installations are vital to national security and the local economy of Oklahoma. However, like most of DoD's installations located in storm-prone areas, these are predisposed to hazardous weather conditions that threaten day-to-day operations. Fort Sill and Tinker AFB served as case studies to explore the impacts of extreme weather on military installations. Both installations are required to use Air Force Weather data for forecasting and decision making. Still, they use a variety of data sources as supplementary to make weather-related decisions. Weather-related decisions are unit-specific and based on the weather event. Winter weather, floods, fire weather, severe thunderstorms, lightning, and excessive heat caused the most disruption to installations.

The impacts of extreme events ranged from cancellations or delays of training of missions to closure of installations to non-essential staff. These events were often expensive in repair costs or damages. The installations had scheduled short and long-term training to prepare for extreme events. Multi-disciplinary collaboration is needed between researchers and the DoD to assess risks. This collaboration will lead to the design and implementation of products, models, training, tools, and engineering of facilities to withstand events such as floods and tornadoes that are the most damaging.

4.9 Study Limitations and Future Work

This study revealed the experiences of personnel in charge of weather-related decisions at Military Bases in Oklahoma. Although the study explored the impacts of extreme weather on installations, all aspects of these impacts could not be discussed and addressed. I could not extend data collection to all five federal installations due to lack of participation because of the sensitive nature of extreme events and threats to national security, frequent leadership turnover, scheduling conflicts, and the impacts of the Covid-19 pandemic at the time of data collection. One significant advantage of using focus groups is what is known as the synergistic effect. Scholars have proposed that this effect results in more information being generated than in other methods. However, because questions needed to be vetted ahead of time, there was some loss of the interactive aspect of focus groups and the opportunity for participants to explore different points of view and formulate and reconsider their ideas and understanding.

Future work would have to focus on expanding interviews and focus groups, as well as including workshops, to foster discussions and engagement with these installations. Personnel in charge of unit-specific decisions should also be included in the study. Finally, researchers will have to make compromises and trade-offs on conducting actionable research to understand and help the military combat climate change and what details can be shared, reported, or published.

4.10 References

Acclimatise UK and UA SERDP Project RC-2232 Team, 2015: Climate Change Impacts to Department of Defense Installations-Barry M. Goldwater Range Climate Risks Workshop Summary Report.

Altus AFB, 2019: Altus AFB History. https://www.altus.af.mil/About-Us/CommandersCorner/ (Accessed May 11, 2019).

Arndt, D., 2005: Oklahoma's Climate: An Overview. Oklahoma Climatol. Surv., 8.

Ashley, S. T., and W. S. Ashley, 2008: Flood fatalities in the United States. J. Appl. Meteorol. Climatol., 47, 805–818, https://doi.org/10.1175/2007JAMC1611.1.

Boone, M., L. Kos, and M. A. Shafer, 2019: Weather and Climate Impacts on Military Operations Workshop Summary. 20 pp. http://www.southernclimate.org/documents/MilitaryOperationsWorkshop.pdf.

Boruff, B. J., J. A. Easoz, S. D. Jones, H. R. Landry, J. D. Mitchem, and S. L. Cutter, 2003: Tornado hazards in the United States. Clim. Res., 24, 103–117, https://doi.org/10.3354/cr024103.

Brown, S., P. Archer, E. Kruger, and S. Mallonee, 2002: Tornado-related deaths and injuries in Oklahoma due to the 3 May 1999 tornadoes. Weather Forecast., 17, 343–353, https://doi.org/http://dx.doi.org/10.1175/1520-0434(2002)017<0343:TRDAII>2.0.CO;2.

Busby, J., 2008: Who cares about the weather?: Climate change and U.S. national security. Secur. Stud., 17, 468–504, https://doi.org/10.1080/09636410802319529.

CDC, 2019: About Extreme Heat. Centers Dis. Control Prev.,. https://www.cdc.gov/disasters/extremeheat/heat_guide.html (Accessed December 11, 2019).

Chadwick, B., and Coauthors, 2011: A framework for sea level rise vulnerability assessment for southwest U.S. military installations. Ocean. - MTS/IEEE Kona, Progr. B., https://doi.org/10.23919/OCEANS.2011.6107212.

Chiappe, J., 2011: Oklahoma's Five Military Installations: An Economic Impact Report. 30 pp.

EPA, 2022: Climate Change Indicators: Heat-Related Deaths. https://www.epa.gov/climate-indicators/climate-change-indicators-heat-related-deaths?msclkid=7f9a31edc01e11ec97e6aa8d1189c059 (Accessed March 19, 2022).

FCOE, 2019: FCOE 2019 Information Guide. https://sill-www.army.mil/assets/doc/perspective.pdf (Accessed April 11, 2019).

FEMA, 2022: Disaster Declarations by State/Tribal Government. Fed. Emerg. Manag. Assoc.,. https://www.fema.gov/disasters/state-tribal-government/ (Accessed March 8, 2022).

Garfin, G., and Coauthors, 2021: A new mission: Mainstreaming climate adaptation in the US Department of Defense. Clim. Serv., 22, 100230, https://doi.org/10.1016/J.CLISER.2021.100230.

Garfin, G. M. G. ., and Coauthors, 2017: Assessing Climate Change Risks : Lessons learned from DoD installations in the Southwestern United States. Elsevier, 95 pp.

Gensini, V. A., and H. E. Brooks, 2018: Spatial trends in United States tornado frequency. npj

Clim. Atmos. Sci. 2018 11, 1, 1–5, https://doi.org/10.1038/s41612-018-0048-2.

Gruntfest, E., and J. Handmer, 1999: Coping with flash floods. 1st ed. Springer Science, 322 pp.

Hocker, J. E., A. D. Melvin, K. A. Kloesel, C. A. Fiebrich, R. W. Hill, R. D. Smith, and S. F. Piltz, 2018: The evolution and impact of a meteorological outreach program for public safety officials : An update on the Oklahoma mesonet's ok-first program. Bull. Am. Meteorol. Soc., 99, 2009–2024, https://doi.org/10.1175/BAMS-D-17-0100.1.

Laferance, A., 2015: Supercomputers, Tornadoes, and the Biggest Unsolved Mystery in Weather Technology. The Atlantic, November.

MCAAP, 2019: McAlester Army Ammunition Plant In-Depth Overview. https://installations.militaryonesource.mil/in-depth-overview/mcalester-army-ammunition-plant (Accessed April 11, 2019).

Moss, R., B. Kravitz, and A. Delgado, 2017: Nonstationary Weather Patterns and Extreme Events: Informing Design and Planning for Long-Lived Infrastructure.

Na-Yemeh, D. Y., C. A. Fiebrich, J. E. Hocker, and M. A. Shafer, 2022: Assessing the Impacts of a Weather Decision Support System for Oklahoma Public Safety Officials. Weather. Clim. Soc., 1, https://doi.org/10.1175/WCAS-D-21-0086.1.

NCEI, 2020: Extreme Events. NOAA Natl. Centers Environ. Inf.,. https://www.ncdc.noaa.gov/climate-information/extreme-events (Accessed February 11, 2021).

——, 2022: SCEC Records. Natl. Centers Environ. Inf.,.

https://www.ncdc.noaa.gov/extremes/scec/records/ok/all (Accessed April 10, 2022).

NWS, 2022a: Oklahoma Tornadoes. Natl. Weather Serv.,. https://www.weather.gov/oun/tornadodata-ok-2021 (Accessed March 14, 2022).

——, 2022b: Weather Related Fatality and Injury Statistics. Natl. Weather Serv.,. https://www.weather.gov/hazstat/ (Accessed March 14, 2022).

Oklahoma Climatological Survey, 2011: Oklahoma Monthly Climate Summary, August 2011.

Oklahoma Mesonet, 2022: Top 20 Extreme Weather Events in Mesonet History. http://www.mesonet.org/20th/.

Olson, W., 2021: Pentagon aims to appraise climate hazards at major US bases within a year. https://www.stripes.com/theaters/us/pentagon-aims-to-appraise-climate-hazards-at-major-us-bases-within-a-year-1.670845 (Accessed February 8, 2022).

Paul, S. H., H. O. Sharif, and A. M. Crawford, 2018: Fatalities Caused by Hydrometeorological Disasters in Texas. Geosci. 2018, Vol. 8, Page 186, 8, 186, https://doi.org/10.3390/GEOSCIENCES8050186.

Ratcliff, J., and J. M. K. Smith, 2011: Sea Level Rise Impacts to Military Installations in Lower Chesapeake Bay. Solut. to Coast. Disasters 2011 - Proc. 2011 Solut. to Coast. Disasters Conf., 740–752, https://doi.org/10.1061/41185(417)64.

Ross, T., and N. Lott, 2003: A Climatology of 1980-2003 Extreme Weather and Climate Events. 14 pp. https://www.ncdc.noaa.gov/monitoring-content/billions/docs/lott-and-ross-2003.pdf.

Scott, S. V, and S. Khan, 2016: The Implications of Climate Change for the Military and for Conflict Prevention, Including through Peace Missions. ASPJ Africa Francoph., 7, 82–94.

Smith, A. B., 2019: 2018's Billion Dollar Disasters in Context. Climate.gov,. https://www.climate.gov/news-features/blogs/beyond-data/2018s-billion-dollar-disasters-context (Accessed June 10, 2020).

——, 2020: 2010-2019: A landmark decade of U.S. billion-dollar weather and climate disasters. Climate.gov,. https://www.climate.gov/news-features/blogs/beyond-data/2010-2019-landmark-decade-us-billion-dollar-weather-and-climate (Accessed June 10, 2020).

Smith, W., D. Schultz, D. Whitford, J. Barry, D. Uyesugi, W. Mitchell, and B. Stamey, 2010: Climate Change Planning for Military Installations. http://www.mwcog.org/uploads/committee-documents/ll1dXltf20120515090746.pdf.

SPC, 2022: Annual U.S Killer Tornadoes Statistics. Storm Predict. Cent. - NOAA/National Weather Serv.,. https://www.spc.noaa.gov/climo/torn/fatalmap.php.

Storm Events Database, 2022: Storm Events. Natl. Centers Environ. Inf. -NOAA,. https://www.ncdc.noaa.gov/stormevents/ftp.jsp (Accessed February 12, 2022).

The Oklahoman, 2022: A history of twisters: Tornadoes in Oklahoma. https://data.oklahoman.com/tornado-archive/oklahoma/2022/ (Accessed March 18, 2022).

Tinker Air Force Base, 2017: Economic Impact Statement 2017. https://www.tinker.af.mil/Links/Economic-Impact-Statement/ (Accessed May 11, 2019).

Vance Air Force Base, 2017: Vance Air Force Base , Oklahoma. 3.

Weatherly, J. W., D. R. Hill, and N. Hampshire, 1992: Os-02 : the Impact of Climate and Extreme Weather Events on Military Operations. Security,.

YCC Team, 2021: Extreme weather is costing the military billions of dollars. Yale Clim. Connect.,. https://yaleclimateconnections.org/2021/07/extreme-weather-is-costing-the-military-billions-of-dollars/ (Accessed February 8, 2022).

Ziolkowska, J., 2019: Economic Benefits and Evaluation of Mesonet Information and Tools – Example of OK-FIRE. Amer. Meteor. Soc, Arizona.

Ziolkowska, J. R., and Coauthors, 2017: Benefits and beneficiaries of the Oklahoma mesonet: A multisectoral ripple effect analysis. Weather. Clim. Soc., 9, 499–519, https://doi.org/10.1175/WCAS-D-16-0139.1.

Chapter 5: Conclusion

5.1 Summary

This dissertation used a mixed approach of methods (i.e., survey data, NOAA's Storm Events Database, Google Analytics, focus groups, and interviews) to assess the relevance of environmental weather monitoring and associated training in Oklahoma. The chapters from the dissertation detailed what motivated emergency managers to seek training and information sources related to weather events. The chapters further explored how important (in value and impact) weather training and data were to emergency managers (EMs), and how weather data sources and constraints differed between those in the military and those in local government positions. The quote below is one example of what motivated emergency managers to seek training and information sources related to weather events:

> *"…this is predominant an artillery post, and with artillery, it's very critical to have the meteorological data, and that data helps us calculate the fire solutions of certain weapon systems…" – Fort Sill Fires Center of Excellence*

Previous research highlights that 78% of disasters are weather-related. As such, public safety officials spend a lot of time responding to weather-related disasters even though they may not be trained meteorologists. Emergency managers and public safety officials at all levels are usually tasked with integrating information from different sources and the NWS to make informed decisions in order to protect lives and property. The military also depends on weather data to make decisions, including installation closures, training, and deployment. For example, members of the

OK-First program in various testimonials describe various ways different training and information sources helped them make informed decisions routinely.

Additionally, weather training and data was important both in value and impact to emergency managers as expressed in this testimonial:

> *"I don't know what I'd do without it. I'd probably resign. It's that important." H. Gunter – OK-First Veteran (The Daily Oklahoman –attitude and response to the OK-First program).*

Both the military and those in local government positions reported that weather information is essential and affects them daily. For example, the OK-First program, a weather decision support system in Oklahoma, has become so instrumental in emergency managers' daily operations that users like H. Hunter, quoted above, could not imagine doing his work effectively without it after a significant tornado outbreak.

Military installations also note that their work is often impacted by hazardous weather such that preparedness for these events is something they are aware of and do not take for granted (see quote below). Weather training and data are crucial to military installations. The military invests a lot of money to integrate information from different sources and forecast models to be weather-ready.

> *"…weather seems to be something that is taken for granted by a lot of people. But the extreme conditions, whether it be rain, snow, sleet, ice, or even drought, does have an impact on what we do. And so, even though you may not think you are navigating the weather on a daily basis, we are." – Fort Sill Fires Center of Excellence*

Finally, both the military and EMs in local government reported using various sources to keep them informed about changes to the weather. However, forecasts for military installations are somewhat limited to those derived from Air Force Weather Forecasters (see quote). The only source military installations had to remain consistent with is the National Hurricane Center. Local EMs did not report being similarly constrained.

> *"The Air Force puts a lot of money into these products, so they want to ensure that we're using them. When it comes to experimental products, we don't really dabble into those as much. We're really kind of, like you said, locked on the Air Force weather products and trying to make those better as much as possible"-Tinker AFB*

5.2 Connections to previous literature

Previous studies highlight that public safety officials in emergency management roles integrate a variety of data sources and rely heavily on forecasts to accomplish the goals of their profession (Morss et al. 2008; Stewart et al. 2003). Chapters 2, 3, and 4 described and verified that public safety officials in local government positions and the military are motivated to seek training and information sources related to weather events to accomplish their duties in their jurisdictions and military installations. For example, both officials in local government positions and the military reported using a variety of sources to prepare for hazardous events.

Similar to Hoss and Fischbeck (2016), Weaver et al. (2014), and Doswell (1999), public safety officials operate under varying organizational structures with different constraints. For example, emergency managers in the military are required to use Air Force Weather Forecasts for weather monitoring and decision making. These officials often made recommendations based on forecasts, and each unit made the final call on specific actions to take. In contrast, even though the most common decision made by local government EMs was to ‘inform an official’, several EMs reported being responsible for both finding weather sources and making weather-related decisions. Regardless of the data sources and organizational structure, public safety officials and emergency managers participated in programs such as OK-First to incorporate new resources, collaborate with others, and use new tools and resources to prepare for hazardous weather events.

This dissertation reiterates the value of providing non-scientific audiences with complex meteorological information coupled with well-designed, relevant, and routine training, as Hocker et al. (2018) highlighted. Both military and local EMs reported attending regular training and using resources provided by the military or other agencies such as the OK-First program. These led to several testimonies by both groups of great strides in responses to weather-impacted emergencies (Johnson et al. 2015; Gruntfest and Handmer 1999; Morris et al. 2001). The results demonstrate that weather training and resources enhance situational awareness and increase the ability of officials to make informed assessments and weather-related decisions.

Previous research also indicates societal benefits as a result of access to weather information. However, economic analyses quantifying the benefits of weather information is either missing or scarce (Ziolkowska 2018; Ziolkowska and Zubillaga 2018; Ziolkowska et al. 2017; Giangola 2012; Kenkel and Norris 1995). Therefore, it is advantageous to use various analyses to assess the economic value of weather information, training, and resources. Lawson (2019) argued that these analyses could be applied beyond monetary costs and benefits. The OK-First program provided an ideal opportunity to reveal a deeper understanding of the public safety community and their use of weather information (Baumgart et al. 2008; Baumgart and Bass 2006; James et al. 2000; Morris and Duvall 1999). Two approaches (i.e., self-reported and travel cost) were used to evaluate the societal benefit and economic value of weather information. Both conservative estimates stressed the importance of weather decision support systems for emergency management. Public safety officials in the military also revealed this benefit through investments the Air Force makes in weather information and training to ensure that missions continue as best as possible even with weather-related delays and disruptions - thereby saving time, cost, and resources.

Finally, as emphasized by previous studies (e.g., Garfin et al. 2021, 2017), the DoD recognizes that it faces growing climate risks across its installations. However, factors such as decision-making in a hierarchical organization, prioritized focus on near-term challenges, and frequent turnover in leadership indicate that military installations need opportunities to form mutually beneficial partnerships with external affiliates. As stressed by the authors, there is a need for flexibility of training and collaboration with partners to gain expertise from networks of researchers and stakeholders through tabletop exercises, the OK-First program, and researchers at the University of Oklahoma to help the DoD direct the complex task of navigating its new mission to adapt to climate change.

5.3 Broader implications for weather decision support systems and emergency management

Chapters two and three highlight how important decision support systems are essential for public safety. Officials use them routinely to keep updated on weather changes. These are highlighted in self-reported savings and willingness to travel farther for training. The most crucial attribute of a decision support system is its ability to combine tools, services, training, resources, and follow-up support so officials can make informed and timely decisions.

All three chapters detail how vital weather information is to cost savings and impacts. In paper two, public safety officials reported savings of over $1.2 M using a decision support system. In paper three, officials were willing to pay an average of over $1,000 to assess OK-First training. Further research is needed to fully explore the value of weather decision support systems. In paper three, we could see how weather affects the military's day-to-day operations and resultant impacts in hazardous weather events. Damages were expensive, and disruptions to operations were equally costly. In essence, weather information and training were valuable both in costs and impact regardless of the source of information. The military and the DoD have internal training and varied information sources that help them prepare and manage extreme weather. The military also invests large funds to ensure that military personnel have the information and training to make weather-related decisions.

Local public safety officials often integrate a myriad of resources to achieve this. Programs such as the OK-First have demonstrated how we can incorporate routine training with technology to train public safety officials. Other storm-prone areas can use results of self-reported savings and willingness values to make a case for continued funding and support for this kind of training across the US and especially in storm-prone areas to prepare for, respond to, mitigate against, and recover from hazardous and extreme weather conditions. Results also show regional differences in user needs – and a one size fits all program doesn't work for metrological and weather training. These results suggest that user needs must be routinely integrated when designing and upgrading weather decision support systems.

5.4 Limitations, caveats, and opportunities

The chapters of the dissertation provided relevant first-hand experience and perspective on user interactions with weather data on the local level and in the military and provided economic analyses quantifying the benefits of weather information. Still, a number of things must be taken into consideration when thinking about applying these concepts in similar or different contexts.

First, when assessing the validity and transferability of these results, context is necessary. The research used purposive sampling, and participants had to volunteer to participate. This raised questions about the ability to generalize or transfer findings. Based on interactions with public safety officials and correspondence with automated weather networks, the demand for weather data is high across the country despite the different hazardous weather events. Results discovered from the self-reported and travel cost methods can both be transferred to other states and programs as planning guidance; especially when these events require traveling. In the military context, since this was a case study analysis, more case study samples are needed to verify and corroborate information related to weather events, sources and decisions made. The research herein should be viewed as a pilot and explorative study necessary for emergent research.

Second, when exploring the value of educational programs, it is essential to highlight that the values in these studies are conservative estimates. These self-reported estimates do not consider amounts over $10,000 and values below $10,000. The pilot survey showed that public safety officials struggled to put a value on many decisions they made and could not put a value on estimated savings for lives lost. Categorizing their savings helped them to assess recent decisions they had made. The travel cost method also underestimates the program's value because many participants are in central Oklahoma and do not travel far to attend OK-First training. Techniques such as the zonal travel cost method would help to reflect these estimates better within different zones. Another limitation of the travel cost is that participants cannot be held accountable for their willingness to pay. As such, this may not be an effective way to introduce or implement a fee as used in the traditional travel cost approach. Despite this limitation, this research can be extended to develop a tool for policymakers on how much funding they can provide to keep similar programs running or provide scholarships or reimbursements to promote participation.

Third, the estimates here should not be taken as the total value of the OK-First program but instead viewed as pieces of a puzzle for the calculation of the total value of the OK-first training. The total economic value of the OK-first program would comprise use and non-use valuation techniques. The travel cost method falls within the revealed preference category (real market). Non-use would incorporate contingent valuation and choice modeling methods that use stated preference (hypothetical markets). To capture the total economic value of the OK-First program, more methods must be employed and developed to capture all aspects of assessing impacts of weather decision support systems. These can include bequest values and savings by insurance companies and FEMA (e.g., avoidable costs) that do not have to be paid to individuals because of the use of weather information resources.

Fourth, using an interdisciplinary approach and disparate data sources for these investigations provided several benefits to understanding the relevance of environmental weather monitoring for decision makers. However, there are limitations with comparing results from different instruments such as survey data of 280 public officials and results from interviews and focus groups from two military installations. Survey results from OK-First users provided significantly more robust feedback from al larger sample population. However, in the case of the military, these analyses were done using information from two military installations. There was the additional challenge of dealing with information that could be classified, preventing an in-depth discussion of these same questions. This presents some challenges of under-reporting or underestimating decisions made, sources used and even savings made using Air Force weather data and other supplementary sources.

Fifth, we cannot fully understand the value of the OK-First program without accounting for the benefits of the weather information that non-OK-First users make use of and how they use them. It would be revealing to expand this study to include emergency managers in Oklahoma who are not members of the OK-First program to see what resources they use to make weather-related decisions and if there are any benefits from using those resources. Without this analysis, it would not be easy to appreciate the program's impact fully. I argue, however that OK-First contributes to decision-making for those who can use it to make decisions for their jurisdiction. Only one member represented per agency is needed to make an impact. A such, the goal of this work is not to take away from all those other resources but to highlight the contribution of the OK-First program to public safety officials and decision-making and to encourage other programs to emulate the model to help save lives and property. Moreover, non-participants could benefit from ripple effects as indicated in previous research on the OK-First program. It is also worth noting that the number of active OK-First members (812) is larger than the total number of EMs as reported by the Oklahoma Department of Emergency Management and Homeland Security (350).

5.5 Concluding remarks on extending research

The zonal travel cost method and other methods such as cost-effectiveness decision making (case studies), and damage avoided cost can be used to assess the economic value of weather decision support programs. Also, case study analysis can be extended to include more DoD installations, especially outside Oklahoma, to discover if there are state variations. In addition, surveying other installations can expand on existing knowledge on how extreme events affect day-to-day operations and provide an analysis of costs to operations and physical assets at the DoD. Future studies should also be extended to include personnel who make unit-specific weather-related decisions at military installations. Conversations and compromises will have to be made on the level of collaboration and security needed to foster research with the military. One recommendation is to ensure confidentiality and what can be published during this process in a way that contributes to knowledge while helping the DoD meet its goals to combat climate change.

5.6 References

Baumgart, L. A., and E. J. Bass, 2006: Presenting information in simulated real-time to support part-task weather scenarios. *Conference Proceedings - IEEE International Conference on Systems, Man and Cybernetics*, Vol. 6 of, 5209–5214.

——, ——, B. Philips, and K. Kloesel, 2008: Emergency management decision making during severe weather. *Weather Forecast.*, **23**, 1268–1279, https://doi.org/10.1175/2008WAF2007092.1.

Doswell, C. A., A. R. Moller, and H. E. Brooks, 1999: Storm Spotting and Public Awareness since the First Tornado Forecasts of 1948. *Weather Forecast.*, **14**, 544–557, https://doi.org/10.1175/1520-0434(1999)014<0544:SSAPAS>2.0.CO;2.

Garfin, G., and Coauthors, 2021: A new mission: Mainstreaming climate adaptation in the US Department of Defense. *Clim. Serv.*, **22**, 100230, https://doi.org/10.1016/J.CLISER.2021.100230.

Garfin, G. M. G. ., and Coauthors, 2017: *Assessing Climate Change Risks : Lessons learned from DoD installations in the Southwestern United States*. Elsevier, 95 pp.

Giangola, L. E., 2012: The cost of cleaner water: Linking farmer incentives to conservation outcomes. University of Colorado, Boulder, .

Gruntfest, E., and J. Handmer, 1999: *Coping with flash floods*. 1st ed. Springer Science, 322 pp.

Hocker, J. E., A. D. Melvin, K. A. Kloesel, C. A. Fiebrich, R. W. Hill, R. D. Smith, and S. F. Piltz, 2018: The evolution and impact of a meteorological outreach program for public safety officials : An update on the Oklahoma mesonet's ok-first program. *Bull. Am. Meteorol. Soc.*, **99**, 2009–2024, https://doi.org/10.1175/BAMS-D-17-0100.1.

Hoss, F., and P. Fischbeck, 2016: Increasing the value of uncertain weather and river forecasts for emergency managers. *Bull. Am. Meteorol. Soc.*, **97**, 85–97, https://doi.org/10.1175/BAMS-D-13-00275.1.

James, T. E., P. O. Long, and M. . Shafer, 2000: An independent evaluation of the OK-FIRST decision-support system. *Amer. Meteor. Soc*, 40–47.

Johnson, V., R. Jeffries, G. Byrd, W. Schreiber-Abshire, E. Page, B. Muller, and T. Alberta, 2015: Celebrating comet's 25 years of providing innovative education and training. *Bull. Am. Meteorol. Soc.*, **96**, 2183–2194, https://doi.org/10.1175/BAMS-D-14-00276.1.

Kenkel, P. L., and P. E. Norris, 1995: Agricultural Producers' Willingness to Pay for Real-Time Mesoscale Weather Information. *Source J. Agric. Resour. Econ.*, **20**, 356–372.

Lawson, M., 2019: *Using Economics to Support Climate Adaptation*. https://headwaterseconomics.org/equity/climate-change/economics-climate-adaptation/ (Accessed October 4, 2020).

Morris, D. A., and C. Duvall, 1999: Real-time, An evaluation of the use of weather data by public-safety agencies. *Preprints, 15th Int. Conf. on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology*, 380–383.

——, K. C. Crawford, K. A. Kloesel, and J. M. Wolfinbarger, 2001: OK-FIRST: A meteorological information system for public safety. *Bull. Am. Meteorol. Soc.*, **82**, 1911–

1923, https://doi.org/10.1175/1520-0477(2001)082<1911:OFAMIS>2.3.CO;2.

Morss, R. E., J. K. Lazo, B. G. Brown, H. E. Brooks, P. T. Ganderton, and B. N. Mills, 2008: Societal and economic research and applications for weather applications for weather forecasts. *Am. Meteological Soc.*, 335–346, https://doi.org/10.1175/BAMS-89-3-335.

Stewart, T. R., R. A. Pielke, and R. Nath, 2003: Understanding user decision making and the value of improved precipitation forecasts. *Am. Meteological Soc.*, 223–236, https://doi.org/10.1175/BAMS-85-2-223 In.

Weaver, J., L. C. Harkabus, J. Braun, S. Miller, R. Cox, J. Griffith, and R. J. Mazur, 2014: An overview of a demographic study of united states emergency managers. *Bull. Am. Meteorol. Soc.*, **95**, 199–203, https://doi.org/10.1175/BAMS-D-12-00183.1.

Ziolkowska, J. R., 2018: Economic value of environmental and weather information for agricultural decisions – A case study for Oklahoma Mesonet. *Agric. Ecosyst. Environ.*, **265**, 503–512, https://doi.org/10.1016/j.agee.2018.07.008.

——, and J. Zubillaga, 2018: Importance of weather monitoring for agricultural decision-making – an exploratory behavioral study for Oklahoma Mesonet. *J. Sci. Food Agric.*, **98**, 4945–4954, https://doi.org/10.1002/jsfa.9027.

Ziolkowska, J. R., and Coauthors, 2017: Benefits and beneficiaries of the Oklahoma mesonet: A multisectoral ripple effect analysis. *Weather. Clim. Soc.*, **9**, 499–519, https://doi.org/10.1175/WCAS-D-16-0139.1.

Appendix A: OK-First Survey questionnaire for chapters 2 and 3

Survey Flow

Table of Contents

Page Break

Start of Block: Consent to participate

Q1 **Consent to Participate in Research at the University of Oklahoma**

[OU-NC IRB Number: 11814 Approval Date: March 13, 2020]

You are invited to participate in a research about the **perceptions of applications of OK-First for environmental weather monitoring for public safety and emergency management in Oklahoma**. If you agree to participate, you will complete this **online survey**. There are no risks, benefits or compensation. After removing all identifiers, we might share your data with other researchers or use it in future research without obtaining additional consent from you. Even if you choose to participate now, you may stop participating at any time and for any reason. Data are collected via an online survey system that has its own privacy and security policies for keeping your information confidential. No assurance can be made as to their use of the data you provide. If you have questions about this research, please contact me at 270-421-1224 or dolly.na-yemeh1@ou.edu or Dr. Jad Ziolkowska at (405) 325-9862 or at jziolkowska@ou.edu. You can also contact the University of Oklahoma – Norman Campus Institutional Review Board at 405-325-8110 or irb@ou.edu with questions, concerns or complaints about your rights as a research participant, or if you don't want to talk to the researcher. Please print this document for your records. By providing information to the researcher(s), I am agreeing to participate in this research.

Are you 18 years of age or older?

◯ Yes, I am

◯ No (If no - cannot participate)

Skip To: End of Survey If Consent to Participate in Research at the University of Oklahoma [OU-NC IRB Number: 11814 ... = 2

Page Break

End of Block: Consent to participate

Start of Block: Section 1: About you and engagement with OK-First

Q2

Section 1: About you and engagement with OK-First

Q3 Select the statement that applies to you:

Are you either a current or former OK-First participant?

○ I'm a current OK-First participant

○ I've not participated in the OK-First before

Skip To: Q4 If Select the statement that applies to you: Are you either a current or former OK-First participant? = 1

Skip To: End of Survey If Select the statement that applies to you: Are you either a current or former OK-First participant? = 2

Q4 How many years have you participated in the OK-First program?

- ◯ 1-5
- ◯ 6-10
- ◯ 11-15
- ◯ 16-20
- ◯ More than 20

Q5

Q6 What climate division is your jurisdiction located in? Select all that apply.

- ☐ 1. Oklahoma Panhandle
- ☐ 2. North Central Oklahoma
- ☐ 3. Northeast Oklahoma
- ☐ 4. West Central Oklahoma
- ☐ 5. Central Oklahoma
- ☐ 6. East Central Oklahoma
- ☐ 7. Southwest Oklahoma
- ☐ 8. South Central Oklahoma
- ☐ 9. Southeast Oklahoma
- ☐ Other (please specify) ____

Q7 Which of the following best matches your job/role? Select all that apply.

- ▢ Emergency manager
- ▢ Law enforcement
- ▢ 911/Dispatcher
- ▢ Emergency medical responder
- ▢ Fire official
- ▢ City official
- ▢ County official
- ▢ Tribal official
- ▢ State official
- ▢ Health official
- ▢ Military official
- ▢ School official
- ▢ Non-profit volunteer organization active in disaster
- ▢ Other (please specify) ____

Q8 Approximately how many OK-First classes in total have you attended?

- 1 - 5
- 6 - 10
- 11 - 15
- 16-20
- More than 20

Q9 What is the highest OK-First level you have attained?

- OK-First Certified (attended week-long class)
- OK-First Assistant Certified (attended 2-day class)
- Not sure

Q10 When did you attend your last OK-First class?

- Within the last 6 months
- Between the last 6 and 12 months
- Between 12 and 18 months ago
- Over 18 months ago

End of Block: Section 1: About you and engagement with OK-First

Start of Block: Section 2: Decisions made using OK-First

Q11

Section 2: Decisions made using OK-First

Q12 In terms of importance to your work duties, how do you value the services you receive from OK-First?

	Not at all Important	Slightly Important	Important	Fairly Important	Very Important	No Opinion
The training (the classes)	○	○	○	○	○	○
The technology (website and software)	○	○	○	○	○	○
The follow-up support (troubleshooting when something is not working)	○	○	○	○	○	○
The connections (with NWS, other public safety agencies)	○	○	○	○	○	○
Other (please specify)	○	○	○	○	○	○

Q13 How often do you use the following OK-First/Mesonet tools:

	Daily	Once a week	2 - 3 times a week	More than 3 times a week	Once a month	2 - 3 times a month	More than 3 times a month	Only when there is a weather event	I don't use this
Weather Briefing Webpage	○	○	○	○	○	○	○	○	○
RadarFirst Software	○	○	○	○	○	○	○	○	○
Mesonet App	○	○	○	○	○	○	○	○	○
Mesonet website	○	○	○	○	○	○	○	○	○

Q14 Have you ever made a decision for your jurisdiction using Mesonet data, OK-First tools, or OK-First training?

○ Yes

○ No

Skip To: Q17 If Have you ever made a decision for your jurisdiction using mesonet data, OK-First tools, or OK-Fir... = 1

Skip To: Q15 If Have you ever made a decision for your jurisdiction using mesonet data, OK-First tools, or OK-Fir... = 2

Q15 Which of the following contributed to you **not** using OK-First? Select all that apply.

- ☐ I am not responsible for making weather-related decisions in my office
- ☐ Do not have enough experience with OK-First
- ☐ Not enough time to use OK-First
- ☐ Other: ____

Q16 Could OK-First data and training have supported your office's decision making with any of the following? Select all that apply.

- ▢ Cancel or postpone a major community event (e.g., outdoor concert or sporting event)
- ▢ Cancel or postpone a minor community event (e.g., parade, group meeting)
- ▢ Sound an outdoor warning system for my community
- ▢ Pre-position resources for an impending weather event
- ▢ Close a road or re-routed traffic for an impending flooding event or other significant weather factor (e.g. rerouting 1st Responders due to active tornado path of travel)
- ▢ Inform an official (e.g., mayor, superintendent, County Commissioner, etc.) so that he/she could make community decisions based on an impending weather event
- ▢ Help make a closure or delayed opening decision (school, government offices, etc.)
- ▢ Generate an effective response after an impactful weather event
- ▢ Assist with a construction project (e.g., road, building, etc.)
- ▢ Assist with a law enforcement investigation
- ▢ Initiate or provide a "significant weather potential" update/notice to public officials, general public, etc.
- ▢ Include an OK-First trained staff member in the Emergency Operations Center to provide weather support during an event (scheduled or emergency)
- ▢ Others ____

Skip To: End of Block If Could OK-First data and training have supported your office's decision making with any of the fol... != 1

Skip To: End of Block If Could OK-First data and training have supported your office's decision making with any of the fol... = 2

Skip To: End of Block If Could OK-First data and training have supported your office's decision making with any of the fol... != 7

Skip To: End of Block If Could OK-First data and training have supported your office's decision making with any of the fol... = 12

Q17 Within the **past 12 months**, how many times have you made a decision based on OK-First data or training for your jurisdiction?

	Never (Haven't made a decision)	1 - 5 times	6 - 10 times	More than 10 times
Severe thunderstorms (hail, wind, tornadoes, etc.)	○	○	○	○
Winter weather (snow, ice, wind chills, etc.)	○	○	○	○
Fire weather	○	○	○	○
Flooding	○	○	○	○
Other:	○	○	○	○

Q18 Using OK-First, I have made the following decision(s) (select all that apply):

- ☐ Cancelled or postponed a major community event (e.g., outdoor concert or sporting event)
- ☐ Cancelled or postponed a minor community event (e.g., parade, group meeting)
- ☐ Sounded an outdoor warning system for my community
- ☐ Pre-positioned resources for an impending weather event
- ☐ Closed a road or re-routed traffic for an impending flooding event or other significant weather factor (e.g. rerouting 1st Responders due to active tornado path of travel)
- ☐ Informed an official (e.g., mayor, superintendent, County Commissioner, etc.) so that he/she could make community decisions based on an impending weather event
- ☐ Helped make a closure or delayed opening decision (school, government offices, etc.)
- ☐ Generated an effective response after an impactful weather event
- ☐ Assisted with a construction project (e.g., road, building, etc.)
- ☐ Assisted with a law enforcement investigation
- ☐ Initiation or provision of a “significant weather potential” update/notice to public officials, general public, etc.
- ☐ Inclusion of an OK-First trained staff member in the Emergency Operations Center to provide weather support during an event (scheduled or emergency)
- ☐ Others ____

Q19 Can you give specifics on a particular event or decision made (e.g., date and location of weather event)

____

____

Q20 If you had to make an estimate, how much (in dollars) would you say your OK-First decisions have saved your jurisdiction over the past 12 months?

○ Below $1,000

○ $1,001 - $5,000

○ $5,001 - $ 10,000

○ Over $ 10,000

○ Unsure

Skip To: Q21 If If you had to make an estimate, how much (in dollars) would you say your OK-First decisions have... = 13

Skip To: Q22 If If you had to make an estimate, how much (in dollars) would you say your OK-First decisions have... != 13

Q21 Could you elaborate on why it is difficult to estimate costs for weather related decisions in your jurisdiction?

____

____

Skip To: End of Block If Could you elaborate on why it is difficult to estimate costs for weather related decisions in you... Is Displayed

Q22 While we recognize estimating costs can be difficult, please elaborate on one of your decisions that saved dollars for your jurisdiction.

____

____

____

____

____

End of Block: Section 2: Decisions made using OK-First

Start of Block: Section 3: Costs associated with attending OK-First classes

Q23

Section 3: Costs associated with attending OK-First classes

Q24 Which mode of transport do you typically use to travel to the OK-First classes?

- ○ Personal vehicle
- ○ Work vehicle
- ○ Rental
- ○ Motorcycle
- ○ Bus
- ○ Other mode (please specify) ____

Q25 How many miles does it take you to get from your home to OK-First classes?

____

____

Q26 If you had to travel further for OK-First classes, how many more miles would you be willing to travel?

____

Q27 How much do you typically spend per day on food when you attend the OK-First classes?

____

Q28 If applicable how much do you spend per day on lodging to attend this event?

____

Q29 If you had additional expenses associated with attending OK-First classes, please share what it was and how much.

____

Q30 Do you typically have to take time off work in order to attend OK-First classes?

- ○ Yes
- ○ No

Skip To: Q31 If Do you typically have to take time off work in order to attend OK-First classes? = 1

Skip To: End of Block If Do you typically have to take time off work in order to attend OK-First classes? = 2

Q31 How many hours do you typically have to take off work?

____

End of Block: Section 3: Costs associated with attending OK-First classes

---

Start of Block: Section 4: Other resources you have used

Q32

Section 4: Other resources you have used

Q33 Were there other weather information resources you used before you joined OK-First?

- ○ Yes
- ○ No

Skip To: Q36 If Were there other weather information resources you used before you joined OK-First? = 2

Q34 What weather information resources did you use before joining OK-First?

____

Q35 Which of these weather information resources do you still use?

____

____

Skip To: Q38 If Condition: Which of these weather info... Is Empty. Skip To: Have you attended other workshops wit....

Skip To: Q38 If Condition: Which of these weather info... Is Not Empty. Skip To: Have you attended other workshops wit....

Q36 Do you currently use any products of OK-First along with some other resources or services?

○ Yes

○ No

Skip To: End of Block If Do you currently use any products of OK-First along with some other resources or services? = 2

Q37 What additional (other than OK-First) weather information or resources do you use?

____

____

Q38 Have you ever attended any weather related classes other than OK-First?

○ Yes

○ No

Skip To: Q39 If Have you ever attended any weather related classes other than OK-First? = 1

Skip To: End of Block If Have you ever attended any weather related classes other than OK-First? = 2

Q39 Was there a fee associated with attending these trainings or workshops?

○ Yes

○ No

Skip To: Q40 If Was there a fee associated with attending these trainings or workshops? = 1
Skip To: End of Block If Was there a fee associated with attending these trainings or workshops? = 2

Q40 How much was the fee to attend?

____

End of Block: Section 4: Other resources you have used

Start of Block: Thank you

Q41 Thank you very much for taking time out of your busy schedule to take this survey! Your participation is very much appreciated and valuable for the purpose of my research.

End of Block: Thank you

Appendix B: Impacts of Extreme Events – Interview/Focus discussion Protocol (semi-structured) for chapter 4

Focus Group: Thanks once gain for joining our session to discuss the impacts of extreme weather on Military Installations. Please know that whatever we discuss tonight must be kept confidential.

Interview: Thanks once gain for meeting with ne today to discuss the impacts of extreme weather on Military Installations. Please know that details of the interview will be confidential.

1. With which Military Installation do you work, and what is your role?
2. What sources of information does your facility use to make weather-related decisions?
3. In your experience, which weather events cause the most disruption to your facility?
4. Who makes weather related decisions for your installation?
5. How many times has your facility made a decision based on a forecast or experienced disruption to daily operations between 2015 and 2019? (Severe thunderstorms (hail, wind, tornadoes, etc., Winter weather (snow, ice, wind chills, etc.), Fire weather, flooding, extreme heat, other?)
6. Can you give specifics on a particular event or decision made (e.g., date and location of weather event, and associated costs, if known)?
7. Could you give examples of activities that can be disrupted by the weather (e.g., cancellation of training due to excessive heat, moving an aircraft to a different location due to hail forecast)?
8. Can you give an example of a disruptive weather event and actions your installation took to deal with the event?
9. Can you describe an incident where the warning/absence impacted your operations (damage, loss, and savings)?
10. Could you elaborate on why it is difficult to estimate costs for weather-related decisions in your facility?

11. How much lead time would your facility need to take preparatory action for a potential event? (Severe thunderstorms (hail, wind, tornadoes, etc., Winter weather (snow, ice, wind chills, etc.), Fire weather, flooding, extreme heat, other?)

12. What are you doing to prepare for extreme weather in the short term?

13. What are you doing to prepare for extreme weather in the long term?

14. Is there anything else you would like to add about the impacts of extreme weather on Military installations?

Appendix C: Selected examples of decisions made by OK-First members

1. We have cancelled sporting events, graduation, changed bus routes, postponed investigation on [a] river, advised commissioners to stage equipment for road clearing, closed city parks due to flooding or lightning, Initiated warning systems for high wind events, tornados, and flooding, evacuated neighborhoods for flooding.

2. I have made the decision to sound outdoor warning sirens and to warn the school district to take shelter. [We] sometimes [use it] to notify the general public using social media. We use it for fire danger prediction.

3. Specific dates are difficult to come up with however we use Mesonet/OK-First every weather event to include Fire Weather. We have postponed yearly events that occur in May for sever[e] storms approaching and have assisted in school closure decisions with Board Members. We were able to prepare for historic floods [t]hat occurred in the Sperry area. Just recently we used the OK-First Radar during the storms that came through North East Oklahoma [on] Wednesday and made decisions based off the data. We use mesonet and Radar first with every event, weather potential, and daily operations.

4. Just this year, sirens were sounded in our county/city (Choctaw/Hugo) because of watching the weather on OK-First and the Decision page also. Every year since I began my job as EM Director for Choctaw County, I always use the OK-First [] and leave the screens are up for everyone to see the weather in the EOC (especially severe thunderstorms, tornados). Also, I like the features that can be used in events that can back up the dates, down to the

minute and print out for other departments. The NWS, Mesonet, OK First employees are helpful and help with problems that we may be having or reading the maps.

5. Postponed [] a parade due to significant wind threat. Notified County Official of fire risk on a pipeline construction project with dry conditions and wind threat. Same pipeline weeks later with heavy rain in the past and more rain in weather models, [threatening] to go under [the] road near stream bed and bridge and had a potential for washout of [the] bridge approach.

6. We used the data to place and confirm spotter information, advise spotters and community leaders of track and timing for warning information, and preplacement of response resources to the event. Luckily they were not needed. We also use the information to plot track information for damage assessment. This particular tornado lifted just as it came into our county and produced only minor damage here.

7. On the morning of October 9, 2018, an EF1 tornado went through Midwest City. I had attended OK-FIRST training about two weeks prior. I can state that I was able to recognize radar imagery (BVEL) that demonstrated a couplet -- this gave me enough forewarning to send out an emergency alert through a text-message and phone based system to my organization (Rose State College). While the tornado ultimately did not reach my workplace, it did damage and flip cars at a local strip mall. The RadarFirst software was also instrumental in observing severe weather that had occurred on the evening of August 26, 2019. Through the RadarFirst software, I was able to observe the storm as it approached the College (where we have residents and housing) and issue an emergency notification.

8. May 2019 - Had a Level 2 Dam Emergency involving a high hazard private dam. The continued risk of severe weather and heavy rainfall in the upstream watershed producing excessive runoff threatened to [raise] the lake level, thereby increasing hydrostatic pressure on the damaged area and causing water to flow into the damaged spillway and further eroding the dam. Weather data/information was used to make decisions to preposition emergency resources, determine on-scene staffing levels, and make preparations to evacuate[] downstream residents.

9. I use O[K]-First pretty much all the time, but specifically I used it last week on the 11th of April to monitor the severe weather as it passed across our county. I used it to give a pre-warning for hail and high winds, and then I used the Mesonet tools to anticipate staging spotters.

10. Graduation 2019 Altus - downburst/microburst or isolated tornado event the night of graduation. Postponed for some time but was allowed to complete the event after the storm passage. The school where it was held sustained wind damage and debris damage to the buildings, cars, and patrons. Some injuries were sustained in the event. [It] [c]ould have been worse.

11. Two weeks ago, Cotton County received flash flooding after 2-3 days of heavy rain. It helped to have this resource to not only plan for road closures of flood-prone areas but also helped in getting the information to the appropriate people on the road crews.

12. [T]he flooding of the salt fork river at [T]onkawa… the radar estimates of Grant county rainfall, the QPF for the next two days. I have read the river since 1982 and never had a

flood last as long as the one 2019 May 20 to June 22. [T]he Salt Fork was above flood stage and had three crests. Had it not been for OK-First and all its links to get current forecast and stage information people could have made some bad decisions.

Appendix D: Disaster Declarations between January 2015 and December 2019

Date	Designated Areas (Counties)	Assistance	Relevant Information
Incident period: May 07, 2019, to June 09, 2019 Major Disaster Declaration declared on August 07, 2019	Muscogee (Creek) Nation: Tulsa, Wagomer, Creek, Okmulgee, Muskogee, Okfuskee, Hughes, Macintosh	Public Assistance: Primary Impact- Emergency protective measures, Total Public Assistance cost estimate-$788,507, Per capita impact - $9.15, Per capita impact indicator- $1.50	Categories A- G requested
Incident period: April 30, 2019, to May 01, 2019, Major Disaster Declaration declared on July 12, 2019	Alfalfa, Atoka, Bryan, Coal, Craig, Kay, Lincoln, Love, Mayor, Noble, Nowata, Okmulgee, Osage, Ottawa, Pittsburg, Pushmataha, Stephens, and Tillman	Individual Assistance: Est. $2,717,526 Total Number of Residences impacted: 199 (Destroyed-44, Major damage-61, minor damage-51, affected-43 Public Assistance: Primary Impact - Damage to roads and bridges Total Public Assistance cost estimate-$7,057,998 Per capita impact - $1.88, Per capita impact indicator- $1.50	Total Public Assistance Grants Dollars Obligated: $1,200,734.38 Emergency Work (categories A-B): $97,102.43 Permanent Work (Category C-G): $702,794.78
Incident period: May 07, 2019, to June 09, 2019 Major Disaster Declaration declared on June 01, 2019	Alfalfa, Canadian, Cherokee, Craig, Creek, Delaware, Garfield, Kay, Kingfisher, Le Flore, Logan, Mayes, Muskogee, Noble, Nowata, Okmulgee, Osage, Ottawa, Pawnee,	Individual Assistance Applications Approved: 2,197 Total Individual & Households Program	Individual Assistance - Dollars Approved : $15,479,162.47-Total Individual & Households Program (IHP) - Dollars

	Payne, Pottawatomie, Rogers, Sequoyah, Tulsa, Wagoner, Washington, Woods	Dollars Approved: $15,479,162.47 Total Public Assistance Grants Dollars Obligated: $10,709,205.63	Approved*$13,260,519.88 - Total Housing Assistance (HA) - Dollars Approved* $2,218,642.59 -Total Other Needs Assistance (ONA) - Dollars Approved* 2,197 - Total Individual Assistance (IA) - Applications Approved* Public Assistance - Dollars Approved $10,709,205.63 - Total Public Assistance Grants (PA) - Dollars Obligated $2,564,324.72- Emergency Work (Categories A-B) - Dollars Obligated $7,700,157.02- Permanent Work (Categories C-G) - Dollars Obligated
Incident period: April 11, 2018, to April 20, 2018 Major Disaster Declaration declared on June 25, 2018	Custer, Dewey, Harmon, Roger Mills, Woodward	Individual Assistance: Not Requested Total Number of Residences impacted: 76 (Destroyed-63, Major damage-0, minor damage-0, affected-13 Public Assistance:	Public Assistance - Dollars Approved $5,419,225.17 - Total Public Assistance Grants (PA) - Dollars Obligated $418,199.92 - Emergency Work (Categories A-B) -

		Total Public Assistance cost estimate-$6,832,123 Statewide Per Capita impact-$1.82 Statewide Per Capita Impact Indicator-$1.46	Dollars Obligated $4,679,895.99 -Permanent Work (Categories C-G) - Dollars Obligated
Incident period: May 16, 2017, to May 20, 2017 Major Disaster Declaration declared on July 25, 2017	Alfalfa, Beckham, Cherokee, Coal, Cotton, Delaware, Johnston, Le Flore, Murray, Muskogee, Okfuskee, Okmulgee, Pittsburg, Pontotoc, Roger Mills, Washita	Public Assistance Primary Impact: Damage to roads and bridges Total Public Assistance cost estimate: $6,552,749 Statewide per capita impact: $1.75 Statewide per capita impact indicator: $1.43	Public Assistance - Dollars Approved $4,550,632.76-Total Public Assistance Grants (PA) - Dollars Obligated $575,803.34-Emergency Work (Categories A-B) - Dollars Obligated $3,829,306.42-Permanent Work (Categories C-G) - Dollars Obligated
Incident period: April 28, 2017, to May 02, 2017 Major Disaster Declaration declared on May 26, 2017	Adair, Beaver, Caddo, Cherokee, Cimarron, Craig, Delaware, Dewey, Haskell, Kiowa, Lincoln, Logan, Mayes, Muskogee, Ottawa, Pawnee, Pawnee (OTSA), Pittsburg, Rogers, Sequoyah, Texas, Washita	Public Assistance Primary Impact: Damage to utilities Total Public Assistance cost estimate: $12,775,885 Statewide per capita impact: $3.41 Statewide per capita impact indicator: $1.43	Public Assistance - Dollars Approved $85,924,213.19- Total Public Assistance Grants (PA) - Dollars Obligated $790,671.36-Emergency Work (Categories A-B) - Dollars Obligated $82,339,800.83- Permanent Work (Categories C-G) - Dollars Obligated

Incident period: January 13, 2017, to January 16, 2017 Major Disaster Declaration declared on February 10, 2017	Beaver, Beckham, Blaine, Dewey, Ellis, Harper, Major, Roger Mills, Texas, Woods, Woodward	Public Assistance Primary Impact: Damage to Public Utilities Total Public Assistance cost estimate: $22,678,625 Statewide per capita impact: $6.05 Statewide per capita impact indicator: $1.43	Public Assistance - Dollars Approved $120,514,739.75- Total Public Assistance Grants (PA) - Dollars Obligated $3,759,961.12-Emergency Work (Categories A-B) - Dollars Obligated $113,963,030.63- Permanent Work (Categories C-G) - Dollars Obligated
Incident period: June 11, 2016, to June 13, 2016 Major Disaster Declaration declared on July 15, 2016	Caddo, Comanche, Cotton, Garvin, Grady, Jackson, Stephens, Tillman	Public Assistance Primary Impact: Damage to roads and bridges Total Public Assistance cost estimate: $6,773,594 Statewide per capita impact: $1.81 Statewide per capita impact indicator: $1.41	Public Assistance - Dollars Approved $4,226,556.24-Total Public Assistance Grants (PA) - Dollars Obligated $304,934.78-Emergency Work (Categories A-B) - Dollars Obligated $3,746,277.46-Permanent Work (Categories C-G) - Dollars Obligated
Incident period: December 26, 2015, to January 05, 2016 Major Disaster Declaration declared on February 10, 2016	Adair, Alfalfa, Beckham, Blaine, Caddo, Canadian, Cherokee, Coal, Comanche, Cotton, Craig, Custer, Delaware, Dewey, Grady, Grant, Greer, Harmon, Haskell, Hughes, Jackson, Kay, Kingfisher, Kiowa, Latimer, Major, Mayes, McCurtain,	Individual Assistance Total Number of Residences Impacted: 208 Destroyed - 108 Major Damage - 49 Minor Damage - 20 Affected - 31	Public Assistance - Dollars Approved $49,766,233.94-Total Public Assistance Grants (PA) - Dollars Obligated $1,310,476.70-Emergency Work (Categories A-B) -

	McIntosh, Muskogee, Noble, Okfuskee, Okmulgee, Osage, Ottawa, Pittsburg, Pushmataha, Roger Mills, Sequoyah, Tillman, Washita, Woods	Percentage of insured residences: 4.83% Percentage of low income households: 84.5% Percentage of elderly households: 17.8% Total Individual Assistance cost estimate: $4,340,626 Public Assistance Primary Impact: Damage to public utilities · Total Public Assistance cost estimate: $48,234,107 Statewide per capita impact: $12.86 Statewide per capita impact indicator: $1.41	Dollars Obligated $46,601,356.24-Permanent Work (Categories C-G) - Dollars Obligated
Incident period: November 27, 2015, to November 29, 2015 Major Disaster Declaration declared on December 29, 2015	Alfalfa, Beckham, Blaine, Bryan, Caddo, Canadian, Custer, Dewey, Ellis, Garfield, Grady, Grant, Greer, Kingfisher, Kiowa, Logan, Major, Oklahoma, Roger Mills, Washita, Woods	Public Assistance Primary Impact: Damage to utilities Total Public Assistance cost estimate: $19,701,106 Statewide per capita impact: $5.25 Statewide per capita impact indicator: $1.41	Public Assistance - Dollars Approved $29,609,795.91-Total Public Assistance Grants (PA) - Dollars Obligated $16,040,946.91-Emergency Work (Categories A-B) - Dollars Obligated $12,687,562.00-Permanent Work (Categories C-G) - Dollars Obligated

Incident period: May 05, 2015, to June 22, 2015 Major Disaster Declaration declared on May 26, 2015	Adair, Atoka, Beckham, Bryan, Caddo, Canadian, Carter, Choctaw, Cleveland, Coal, Comanche, Cotton, Craig, Creek, Custer, Delaware, Dewey, Garvin, Grady, Grant, Greer, Harmon, Haskell, Hughes, Jackson, Jefferson, Johnston, Kay, Kingfisher, Kiowa, Latimer, Le Flore, Logan, Love, Major, Marshall, Mayes, McClain, McCurtain, McIntosh, Murray, Muskogee, Noble, Nowata, Okfuskee, Oklahoma, Okmulgee, Ottawa, Pittsburg, Pontotoc, Pottawatomie, Pushmataha, Roger Mills, Seminole, Sequoyah, Stephens, Tillman, Wagoner, Washita	Individual Assistance Total Number of Residences Impacted: 828 Destroyed - 157 Major Damage - 237 Minor Damage - 168 Affected - 266 Percentage of insured residences: 34.18% Percentage of low-income households: 32.85% Percentage of elderly households: 12.8% Total Individual Assistance cost estimate: $7,540,253	Individual Assistance Applications Approved: 4,610 Total Individual & Households Program Dollars Approved: $18,563,163.18 Total Public Assistance Grants Dollars Obligated: $66,106,773.52

Appendix E: Linear Regression Assumptions and Diagnostics

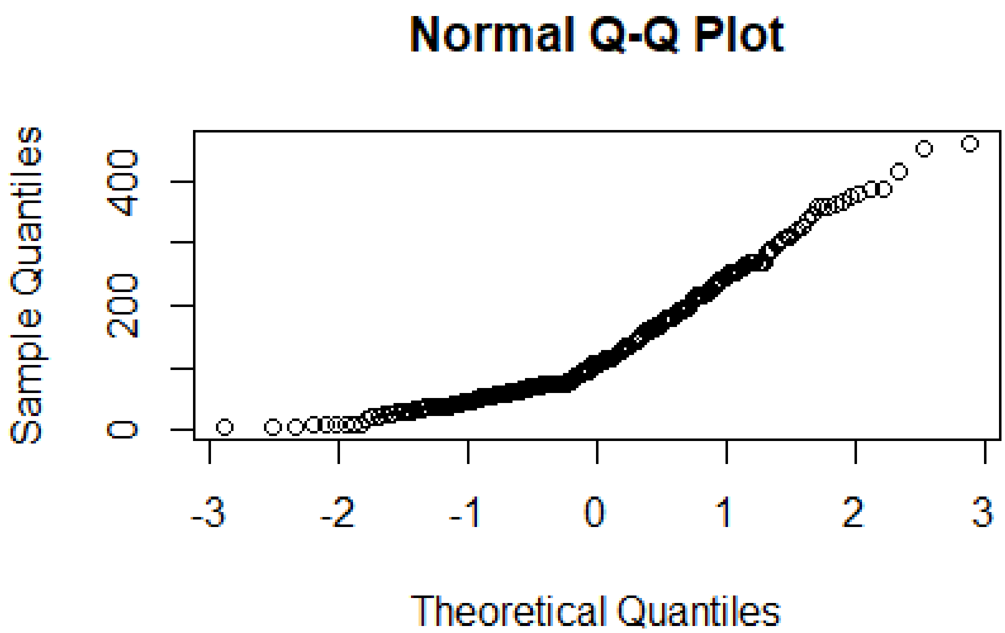

Figure A-1: Normality of residuals for *Pactual*

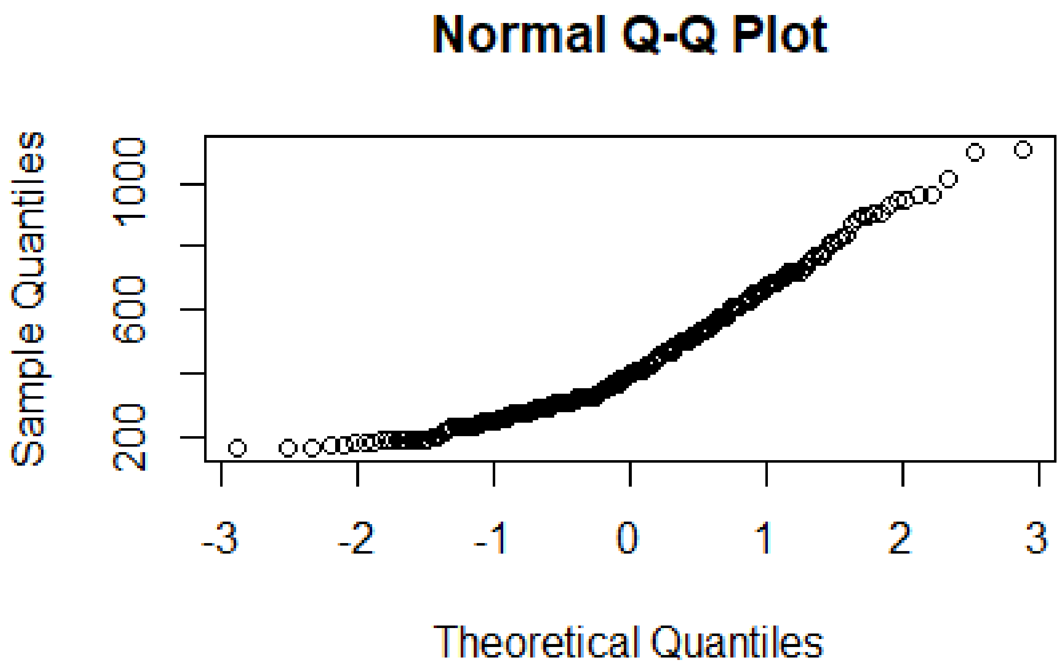

Figure A-2: Normality of residuals for *Pwilling*

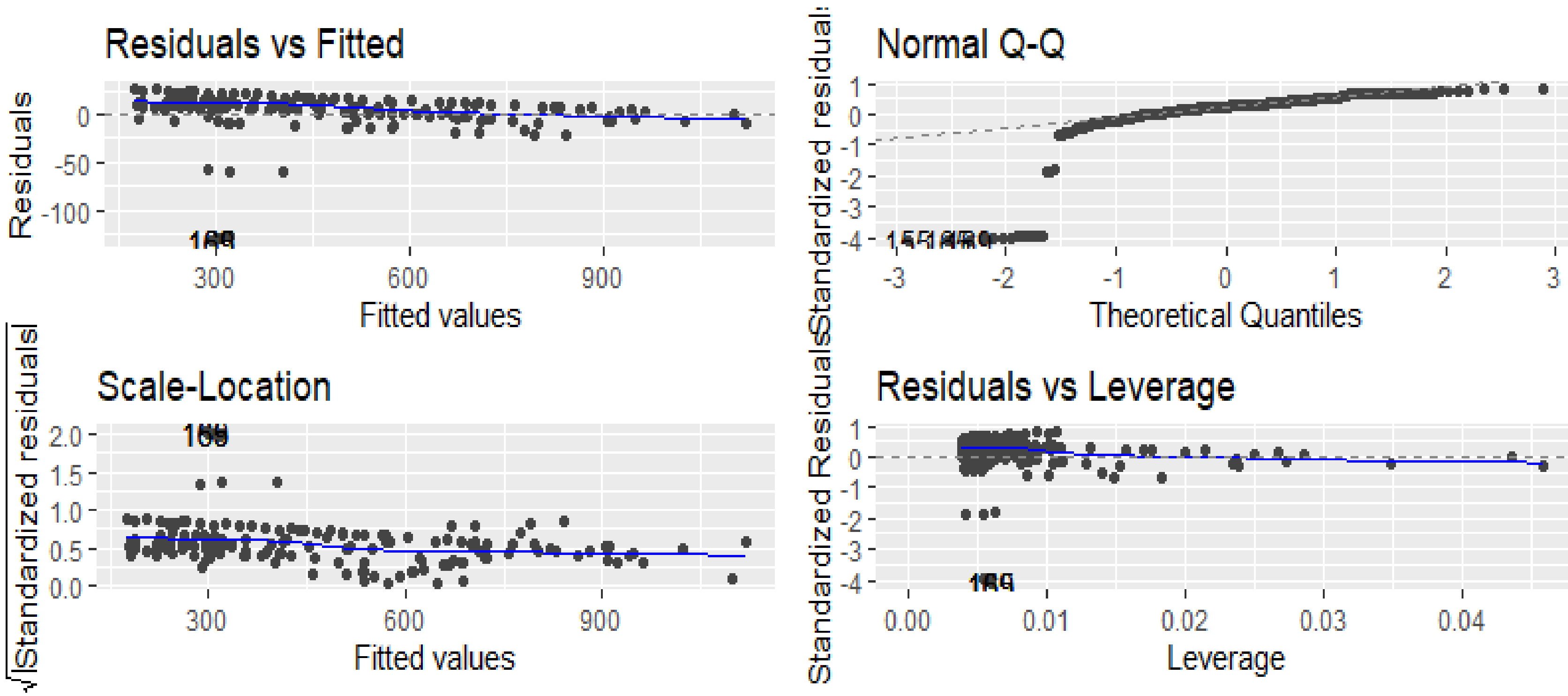

Figure A-3: Diagnostics plots for regression assumptions for willingness and actual travel costs

Appendix F: Thematic parent codes and descriptions for chapter 4

Code	Description
Climate change	Discussions on connections of extreme events and changing climate, DoD efforts in OK
Costs and impacts	Costs and impacts of hazardous weather events
Decision makers	Who makes weather related decisions and what criteria is used
Disruptions and Decisions	E.g., number of times facility has made a decision based on a forecast or experienced disruption to daily operations
Lead time	Time needed to prepare for hazardous weather conditions
Preparedness	What installations are doing in the long and short term to prepare for extreme weather
Quote	Direct quotes about the impact of extreme weather and related issues
Rationale	Reasons weather is important, reason for using sources they use, reasons for preference over one resource over the other, explanation for AOI
Research opportunities	Areas more research is needed, potential collaborations with affiliates
Roles	Roles and responsibilities of participants at military Installation
Savings or losses	Similar to impacts but focused on specific decisions that saved lives and property
Sources	Sources of weather information used at installations
Types of weather events	Examples of events that affect installations
Weather based decisions	Examples of decisions made based on extreme weather conditions

Appendix G: Recruitment document for chapter 4

University of Oklahoma Research Study

Impacts of Extreme Weather Events on Military Installations in Oklahoma

Principal Investigator: Dolly Na-Yemeh
Supervisor: Dr. Mark Shafer

You are being asked to volunteer for this research study because you have participated in an OK-First training, tabletop exercise, or workshop at the NWC. Your contribution is essential to this project's success because of your role in emergency management preparedness in a Military Installation in Oklahoma. The purpose of the study is to understand how individual extreme weather events may affect personal safety, physical infrastructure, training schedules, and operations and how those events add up over time for Military Installations.

I am hoping that you will be able to provide a little more information about the impacts of extreme weather events on military installations and would like to invite you to participate in a 60-minute virtual focus group with other people who attend.

If your schedule does not permit this, then we could set up a 60-minute virtual interview at your convenience to discuss how individual extreme weather events may affect personal safety, physical infrastructure, training schedules, and operations for your installation.

If you would be willing to participate in the **focus group**, please let me know and I will send a follow up email to find out about the best day and time to schedule the group meeting.

If you would prefer to schedule an **individual interview**, please suggest a couple days and times that are most convenient for you and I will coordinate my schedule. After removing all identifiers, we might share your data with other researchers or use it in future research without obtaining additional consent from you. You can receive a copy of the final report upon request by emailing Dolly Na-Yemeh, dolly.na-yemeh1@ou.edu, or Dr. Mark Shafer (405) 325-3044 or at mshafer@ou.edu.

If you have questions about this research, please contact me, Dolly Na-Yemeh, at 270-421-1224 or dolly.na-yemeh1@ou.edu or Dr. Mark Shafer at (405) 325-3044 or at mshafer@ou.edu.

If you have any questions about your rights as a research participant and wish to talk to someone other than individuals on the research team, or if you cannot reach the research team, you may contact the University of Oklahoma – Norman Campus Institutional Review Board (OU-NC IRB) at 405-325-8110 or irb@ou.edu. This study has been approved by the University of Oklahoma, Norman Campus IRB.

IRB Number: **13284** Approval date: **04/14/2021**

Yours Sincerely,

Dorothy (**Dolly**) Yemaa Na-Yemeh
Department of Geography and Environmental Sustainability
100 East Boyd Street
Norman, Oklahoma 73019