PROTECTIVE ACTION DECISION MAKING AND THE OROVILLE DAM INCIDENT

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THE OROVILLE DAM INCIDENT

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DEDICATION

To my son, Amari – A kind gentleman once told me you would become someone asking the questions we have not even yet imagined. I believe him. Explore the world around you, travel, engage with new people and new ideas. Ask and seek answers to the hard questions, the ones my generation cannot imagine.

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Abstract: Water resources infrastructure, including dams, provide significant benefits to the United States, but infrastructure also come with risks. Managing infrastructure risk requires an understanding of evacuation decision making including, how and when people evacuate, and what factors contribute and influence decisions to evacuate. Research to date primarily focuses on hurricane evacuation decision making. This study seeks to identify the factors that best explain warning diffusion, protective action initiation delay time, and protective action initiation and what people did during protective action delay time using data collected after the Oroville Dam incident in 2017. A time phased model of protective action decision making was applied to the study sample, which included two at-risk populations downstream of Oroville Dam: Population A, which includes households in Butte County, and Population B, which includes households in Sutter and Yuba Counties. The study found that distance from the dam was a factor in believing the spillway would break and their town and home would flood in Population A. Most demographic characteristics did not reflect decision making. However, income predicted warning receipt time and protective action initiation time in Population B. Income, as well as risk belief, risk perception, decision-making, distance, and warning receipt time predicted evacuation in Population A. Race, message believability, and decision-making predicted evacuation in Population B. In both Population A and Population B warning receipt time predicted protective action initiation time, which suggests that delays in issuing warning and warning diffusion rates delay evacuation. Message believability also predicted protective action initiation time in Population B. In Populations A and B, people sought additional information using a cell phone call; the primary sources for information were friends, relatives, neighbors, and co-workers. Both populations took time to pack items to take with prior to evacuating. The findings of this study will assist emergency managers, infrastructure managers, and government officials to better understand protective action decision making and improve evacuation rates, which in turn can save lives.

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CHAPTER I

INTRODUCTION

Infrastructure, including dams, play an important role in water resource development, including municipal and industrial water supply, recreation, and storing flood waters; however, in the process of altering floodplains to serve other needs, risks are introduced or transformed such as is the case with dams. When risks are transformed, human risk perception and subsequent behavior also change, impacting how and when individuals take protective action, such as moving out of harm's way, in the face of a dam incident.

Estimating the time necessary to evacuate a population, should a dam incident occur, relies on understanding the human decisions that lead to evacuation. The Protective Action Decision Model (PADM) provides a way to organize human behavior and decision-making research (Lindell, 2018; Lindell & Perry, 2012). However, the PADM does not estimate the time it takes to decide to take protective action. The Time Phased Model of Warning and Response measures key periods of time in warning and response (Sorensen & Mileti, 2014a, 2014b, 2014c, 2018; Urbanik, 2000; Urbanik, Desrosiers, Lindell, & Schuller, 1980). Evacuation away from a hazard consists of four time periods: hazard identification, warning issuance delay, warning diffusion, and protective action initiation (Mileti & Sorensen, 1990; Sorensen & Mileti, 2014a, 2014b, 2014c, 2018; Urbanik, 2000; Urbanik et al., 1980). The estimates for each time period inform life loss estimates (Jonkman, 2007, 2016; Jonkman & Kelman, 2005; Kolen, 2016; Mauro, Bruijn, & Meloni, 2012; Needham, Fields, & Lehman, 2016).

United States government agencies calculate estimated life loss using flood characteristics, warning and evacuation time periods, and protective action success during evacuation. The information informs multimillion-dollar actions to manage risks associated with dams (Feinberg, Engemoen, Fiedler, & Osmun, 2016; United States Corps of Engineers [USACE], 2014). The underlying premise in the use of life loss estimates is to avoid increasing the fatalities rates of the population due to risks associated with infrastructure, or stated another way, to avoid infrastructure posing an intolerable risk on the population. This is not to say that infrastructure cannot or will not fail or pose a hazard itself, but that to the extent possible, the owner-operator needs to try to avoid and manage risks imposed on the population by the infrastructure.

This study seeks to identify the factors that best explain warning diffusion, protective action initiation delay time, and protective action initiation and what people do during protective action delay time. Anticipating human behavior can help save people's lives during flood events, including those resulting from dam failure. Improved understanding of decision making will allow dam owner and operators, emergency managers, and other officials responsible for evacuations use their understanding of evacuation behaviors to perform better advanced predictive modeling during risk assessments, improve emergency exercises, and plan for the time necessary to evacuate.

CHAPTER II

LITERATURE REVIEW

This literature review begins by placing dams in a risk context, including introducing the Oroville Dam incident. Then, it will examine the literature of the Time Phased Model of Warning and Response (Sorensen & Mileti, 2014a, 2014b, 2014c, 2018; Urbanik et al., 1980) and the Protective Action Decision Model (Lindell, 2018; Lindell & Perry, 2012). The last section discusses evacuation studies. Finally, the research questions and hypothesis for this study are introduced.

2.1 Dam Risks

Federal agencies, such as the United States Army Corps of Engineers (USACE) and Bureau of Reclamation (BOR), utilize estimates of life loss as a part of their understanding of the risks an existing dam poses to the public. The estimates are used to evaluate and compare the benefits of structural modifications and nonstructural alternatives, such as evacuation, to manage the risks associated with the dam (DeKay & McClelland, 1993). Multiple definitions of risk exist; however, risk generally is defined as the function of the probability of some event occurring and the consequence of that event (Fischhoff, Watson, & Hope, 1984; Jaeger, 2001; Jonkman, 2007; Mauro et al., 2012; Slovic, 2003; Slovic, Fischhoff, & Lichtenstein, 1977; Tierney, 2014). Some definitions also incorporate uncertainty. For the purposes of this paper, risk is "a situation or event in which something of human value (including humans themselves) have been put at stake and where the outcome is uncertain" (Jaeger, 2001, p. 17). Risk analysis provides a systemic way to apply theories and methods from a variety of disciplines for the "purpose of collecting and interpreting data and drawing conclusions about" hazards (Stern & Fineberg, 1996, p. 214).

Evaluating risks posed by infrastructure, including dams, requires that the situation or event that could cause harm include both the hazard agent (flood) and performance of infrastructure. Flood risk often times includes performance of the infrastructure; however, considering performance separately reduces the biased assumption of perfect performance when weaknesses in and between systems are known (Cutter et al., 2013). In other words, dams store water in a reservoir behind the structure, and a dam failure on an otherwise 'sunny day' or during a rain event can result in harm to something of human value. Dam failure is characterized by the "set of events leading to sudden, rapid, and uncontrolled release of the reservoir impoundment" (USACE, 2014, p. 18-2). Significant uncertainty underlies dam incidents (Cox Jr, 2012). While dam safety professionals perform Potential Failure Mode Analysis (PFMA) and some subsequently make estimates of the risks associated with dam failure (Feinberg et al., 2016; USACE, 2014), the timing of when a failure, or near failure, will occur and magnitude of the consequences remains unknown and uncertain until the event occurs (Kasperson, 2009; Paté-Cornell, 1996; Paté-Cornell, 2002; Sorensen & Mileti, 1987).

Federal policy defines the components of flood risk as hazard; performance; exposure of people, property, and the environment; vulnerability of the exposed population, property, and the environment; and consequence or magnitude of harm (USACE, 2014). Flood hazard is the recognition of the water as a source of danger, such as the physical loading or water levels on the dam. Performance refers to how infrastructure systems react when stressed by the hazard, such as the probability of a dam failing prior or subsequent to water flowing over the top of the dam. Hazard exposure refers to who or what might be harmed, generally people, property, and the environment (USACE, 2014). Vulnerability refers to how susceptible the exposed people, property, and environment are to harm (Dennis S Mileti & Sorensen, 1990). The magnitude of harm to the exposed people, infrastructure, and environment makes up the consequence.

While detection of a hazard or nonperformance of infrastructure often is the result of direct observation, an individual downstream of a dam usually will not directly observe a dam incident and know to take protective action. Most warnings will come from emergency mangers or other officials responsible for issuing warnings to the public (Drabek, 2013). In part this is because dam incidents can occur during sunny or rainy-day events. For example, Teton Dam failed on a sunny June day (Independent Panel to Review Cause of Teton Dam, 1976). Even though there are case studies and investigations that focus on dam failure mechanisms, warning downstream populations, and life loss (Becker et al., 2007; Foster, Fell, & Spannagle, 2000; Graham, 2009; Independent Panel to Review Cause of Teton Dam, 1976; Sherard, 1987), few studies exists on how, when, and what factors influence taking protective action by populations downstream of dams.

2.1.1 Oroville Facility

The California Department of Water Resources (DWR) owns and operates the California State Water Project (SWP) (California Department of Water Resources, 2019). Within DWR, the Division of Safety of Dams (DSOD) operates all 22 dams associated with the SWP, and 11 of the dams are also regulated by the Federal Energy Regulatory Commission (FERC) (France et al., 2018). Oroville is a part of the SWP and regulated by FERC (France et al., 2018).

Oroville dam is a 770-foot-tall, earthen embankment, high hazard dam located on the Feather River in Butte County, California. The Oroville facility "consists of an embankment dam, the Oroville Flood Control Outlet, Oroville emergency spillway, Hyatt Powerplant, River Value Outlet System, and the Palermo Tunnel and Outlet" (see Figure 1) (France et al., 2018, pp. 7-8). According to the U.S. Society on Dams, Oroville is the tallest dam in the United States and construction was completed in 1968. The facility and its reservoir serve multiple purposes. In addition to flood risk reduction, the facility provides water conservation, power generation, recreation, and fish and wildlife management (France et al., 2018).

Figure 1. Oroville Dam Facility (prior to February 2017 incident)

Source: The Independent Forensic Team Report, January 2018

Potential Failure Modes Analysis (PFMA) provides dam safety professionals one way to identify the ways in which a dam might fail, and PFMAs were conducted on Oroville Dam in 2004, 2009, and 2014 (France et al., 2018). The spillway failure mode was only identified in the 2014 PFMA, but it was not judged to cause uncontrolled release of the reservoir and downstream flooding (France et al., 2018).

2.1.2 Summary of the Oroville Dam Incident

The recent spillway incident at Oroville Dam provides an opportunity to study human protective action behaviors as a result of a near miss dam failure incident (J. H. Sorensen & Mileti, 2018). California experienced a very wet winter in 2016-2017 (Sorensen & Mileti, 2018). The Independent Forensics Team Report describes in significant detail the flows experienced by the service spillway in January and February 2017, which were the first significant flows since 2011 (France et al., 2018). From February 6-10, nearly 13 inches fell on the Feather River Basin (Sorensen & Mileti, 2018).

On February 7, onsite DWR personnel noticed a disturbance in the service spillway chute flow (France et al., 2018), which lead to closing of the service spillway gates, and the observance of slabs missing from the service spillway chute. The Butte County Sheriff was notified; however, the Sheriff learned of the hole in the spillway chute through social media (Sorensen & Mileti, 2018). DWR and the Sheriff informed the public using social media while DWR, Federal Energy Regulatory Commission (FERC), and other dam safety agencies consulted and the service spillway was monitored (Sorensen & Mileti, 2018). After examining the damage, DWR operated the service spillway in order to "test service spillway capabilities in the damaged condition" (France et al., 2018, p. 25). Sorensen and Mileti (2018) report that Butte County Sheriff issued public information bulletins to the at-risk population downstream on February 9th and 11th.

On February 11th, water began flowing over the emergency spillway in order to minimize the spillway erosion (Sorensen & Mileti, 2018). The emergency spillway flows channelized across the natural terrain, causing erosion and head cutting towards the emergency spillway crest structure causing DWR to open the service spillway gates more and issue an evacuation order downstream (France et al., 2018). DWR was managing the flows with a damaged spillway and head cutting of the emergency spillway, while trying to keep tailwater from the spillway discharges out of the Hyatt Powerplant, and without having the spillway erosion cause failure of a power transmission tower to the right of the service spillway chute (France et al., 2018). It was critical to avoid losing the power plant and transmission lines in order to continue to adjust the releases from the dam.

On February 12th at approximately 3:50 PM, the Butte County Sheriff decided it was time to evacuate the population downstream of Oroville Dam, and the Sherriff notified the Sheriffs of Yuba and Sutter Counties that he was evacuating the at-risk population in Butte County and advised them to do the same (Sorensen & Mileti, 2018). DWR began distributing the evacuation message to safety and emergency managers at 4:10 PM (Sorensen & Mileti, 2018). The Butte County Sheriff issued the first public evacuation message at 4:21 PM, and the National Weather Service issued a Wireless Emergency Alert (WEA) to all three counties at risk at 4:35 PM (Sorensen & Mileti, 2018). Additional targeted messages were issued by various warning officials in Yuba County, Sutter County, Yuba City between 5:33 PM and 6:49 PM (Sorensen & Mileti, 2018).

Flow over the emergency spillway stopped on February 12th at approximately 8:00 PM and on February 14th around 3:30 PM, the evacuation order was downgraded to an evacuation warning (France et al., 2018). The service spillway remained in operation until February 27 in order to reach the target reservoir level (France et al., 2018). In early to mid-March, the evacuation warning was lifted (France et al., 2018).

2.2 Time Phased Model of Warning and Response

As is the case in nearly all risk scenarios, decisions to warn the public and for the public to take protective actions are made under conditions of uncertainty. Sorensen and Mileti (2014a, 2014b, 2014c, 2018) utilized other hazard types to develop warning issuance delay time, warning diffusion time, and protective action initiation delay times. Figure 2 illustrates the time periods used by Sorensen and Mileti (2018), which builds on the four time periods of Urbanik et al. (1980): decision time, notification time, preparation time, and response time (Urbanik, 2000; Urbanik et al., 1980). However, understanding of what happens within each time frame continue to improve, as does the understanding of factors influencing the time frames.

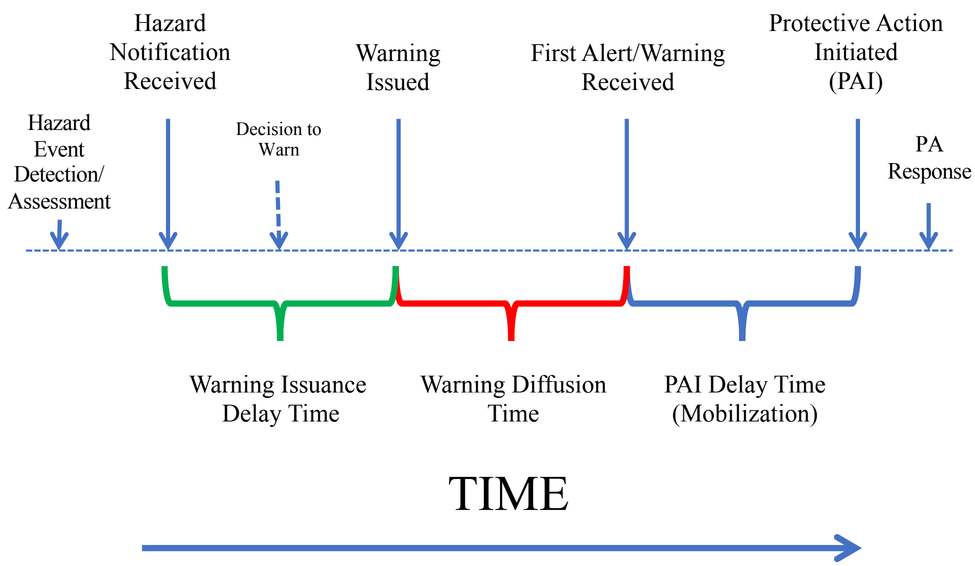

Figure 2. Time Phased Model of Warning and Response

Source: John H. Sorensen & Mileti, 2018

2.2.1 Warning Issuance Delay

Warning issuance delay time is defined as "the period between the point when some form of notification concerning a threat is received by a warning issuance organization and the point that a decision is made to issue warning" (Sorensen & Mileti, 2014a, p. 1). Sorensen and Mileti (2018) revised their conceptualization of warning issuance delay to distinguish between the time between the hazard notification and the decision to warn, and then the time for the message to move through the warning distribution system. Past literature combines those time frames into warning issuance delay. During this time warning official(s), either an individual acting on behalf of an organization or an organization, must reach a decision to issue a warning. The general sequence of issuing a protective action warning follows a similar pattern across researchers (Lindell & Perry, 2012; Perry & Lindell, 2006; Rogers, 1994; Sorensen & Mileti, 1987). Key organizational decision points include the detection of a hazard, determination that the hazard presents a threat, the decision to alert, inter-organizational response, determination of protective action, and public response (Sorensen & Mileti, 1987). Warning issuance delay frequently is not recorded and little research exists to understand the process by which this delay occurs.

Communication within and between organizations presents uncertainty in the information presented, as does lack of clarity regarding whom to notify, how to describe the hazard, and how to deal with conflicting information (Sorensen & Mileti, 1987). Some preparedness plans, especially those involving infrastructure, define trigger points for when a protective action warning would be initiated (Gruntfest & Huber, 1989; Sene, 2010). The trigger points allow for anyone to issue the warning, not just an emergency manager or other warning official(s) and takes the uncertainty of understanding the potential impacts to the population away from a person's risk perception and in to a defined trigger event.

Risk assessments provide valuable information for technically oriented professionals; however, the information must be deliberated upon to inform decisions to issue or heed warning messages by individuals sometimes lacking the technical background that aids with contextualizing risk assessments (Stern et al., 1996). The capacity of an organization or warning official to give and receive information and the uncertainty surrounding that capacity influences warning issuance delay. For example, in the October 1999 landslide dam failure in Poerua River, Westland New Zealand, Becker et al. (2007) found that communication and understanding challenges between the scientific advisor and the Westland District Council may have resulted in delayed evacuation warning.

While most research centers on the risk perception of the people receiving a message of potential harm, warning officials must also perceive harm prior to ordering evacuation warnings and use that perception to inform warning action; this should not be overlooked for its value to understanding the thought process of the warning official. Even technically oriented people apply a lens through which the risk is perceived, rendering risk a social construct with multiple interpretations of the same information (Dash & Gladwin, 2007; Jasanoff, 1998; Lindell, Tierney, & Perry, 2001). The warning official must perceive a risk to a population in order to consider issuing a protective action warning.

2.2.2 Warning Diffusion Time

Warning diffusion is the amount of time it takes from a warning message being issued to when warning is received by the at-risk population (Sorensen & Mileti, 2014b). Warning receipt is predicated on receiving the alert or warning from formal, informal, or unofficial sources (Sorensen & Mileti, 2018). Warning may occur prior to the decision to warn due to environmental or social cues, or informal or unofficial warning (Lindell, 2018; Lindell & Perry, 2012; Sorensen & Mileti, 2018). An example of informal warning is a call or text message from a friend or neighbor, and unofficial sources include news media warning of the possibility of an incident or evacuation order (Sorensen & Mileti, 2018). Warning receipt is influenced by where people are located and what they are doing (Rogers & Sorensen, 1988) as well as the method used to transmit warning (Lindell & Perry, 1987; Mileti & Sorensen, 1990; Rogers & Sorensen, 1988).

Some people are more likely to hear warnings because of their social network, or because their social role connects them to informal warnings (Mileti & Sorensen, 1990). People of high socioeconomic status are more likely to hear a warning (Sorensen, 1991). Sorensen (1991) found that those who lived nearer to the hazard site receive warning earlier than those farther away. Some people may not hear or notice the warning due to “habituation (e.g., they never really listen to television), selective perception (e.g., they hear only what they want to), or physical contains (e.g., they are out of range of the siren system)" (Mileti & Sorensen, 1990b, p. 5-1). Inaccurately recalling the first warning received is also a factor (Lindell, 2018; Lindell & Perry, 2012; Sorensen & Mileti, 2018; Wu, Lindell, & Prater, 2015)

2.2.3 Protective Action Delay Time

Protective action initiation delay time is the time it takes for a person or household to receive warning, until they initiate protective action (Sorensen & Mileti, 2014c). Mileti and Sorensen (1990) describe the warning response process of hearing, understanding, believing, personalizing, deciding, and searching and confirming as an ordered-choice process, even if it is not linear for everyone. Reunification of the household can also occur during this time period (Mileti & Sorensen, 1990). Understanding the message, believing it, personalizing it, and deciding to act are influenced by the characteristics of the warning message. Specificity of the message, including the actions to take, urgency, and risk characteristics, increases the effectiveness of the warning (Dennis S Mileti & Sorensen, 1990).

2.3 Protective Action Decision Model

Evacuation research can be understood using the Protective Action Decision Model (PADM, Figure 3), which lays out the environmental context, personal characteristics, situational facilitators and impediments, and behavioral response processes that affect decisions to take protective action upon receipt of warning (Lindell, 2018; Lindell & Perry, 2012). While the PADM lays out a usual pattern, not all persons undertake all steps, nor do the decisions occur in the order listed in Figure 3 (Lindell, 2018).

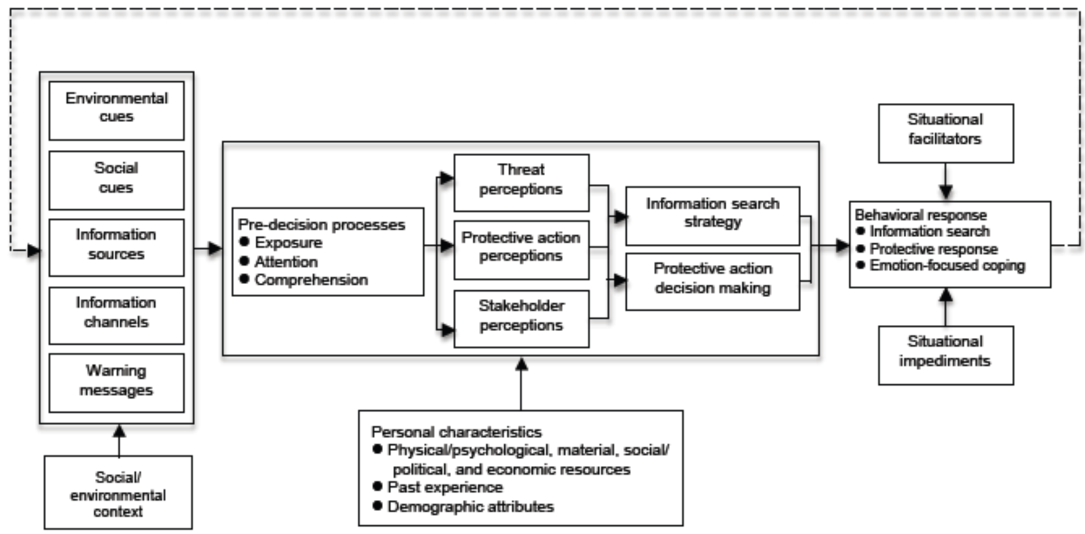

Figure 3. Information flow in the PADM
Source: Lindell (2018)

2.3.1 Social and Environmental Context

The environmental context of decision making includes physical, social, and household components (Lindell, Huang, Wei, & Samuelson, 2016). Physical components include the characteristics of the hazard agent, as well as structures available that could protect or threaten one's safety. For dam incidents, and flooding in general, the protective action necessary varies based on the depth, duration, velocity, and temperature of flood waters. High velocity floods of sufficient depth can move homes off of their foundation, so vertical evacuation might not be successful. Whereas, shallow, low velocity flooding can allow for a person to safely shelter in their home. The social component includes those who can help or inform others, or those who may need assistance (Lindell, 2018). Household component includes the presence or absence of household members (Lindell, 2018). Separated household members seek information regarding those missing, delaying evacuation until they are reunited or agree where to meet (Drabek & Boggs, 1968).

Within the environmental context, environmental cues, social cues, information sources, information channels, and warning messages are the early components in the evacuation decision-making process (Lindell, 2018; Lindell & Perry, 2012). While some people evacuate due to informal or unofficial warnings, government issued warnings facilitate evacuation for many people (Drabek, 2013). The general sequence of issuing a protective action warning follows a similar pattern across researchers (Lindell & Perry, 2012; Perry & Lindell, 2006; Rogers, 1994; Sorensen & Mileti, 1987): first, the hazard must be made known by those whom have observed the hazard through monitoring or by chance; monitoring of the threat occurs, and then the threat is assessed and projections of likely consequences made; finally, the decision to warn (or not) is made and risk communication occurs.

2.3.2 Psychological Processes

The information received within the social/environmental context, then undergoes a psychologic process. Three activities make up the psychological processes—pre-decisional processes; core perceptions (threat perceptions, protective action perceptions, and stakeholder perceptions); and protective action decision making (Lindell, 2018; Lindell & Perry, 2012). Lindell and Perry (2012) identify the psychological processes one undergoes to take protective action (p. 618-619). The pre-decision processes, which include exposure, attention, and comprehension, primarily occur subconsciously (Lindell & Perry, 2012; Wu et al., 2015). Whether the result of environmental or social cues, people will not initiate protective action "unless people receive, heed, and comprehend" the information transmitted (Lindell & Perry, 2012, p. 619).

Core perceptions are the basic frame from which people intake, analyze, and assign meaning to information received, including risk information. Most people "rely on intuitive risk judgments, typically called 'risk perceptions' when assessing risks (Slovic, 1987; Slovic et al., 1977). Risk perception includes considering the likelihood that an individual will personally experience a consequence (Lindell & Perry, 2012). Even technically oriented people apply a lens through which the risk is perceived, rendering risk a social construct with multiple interpretations of the same information (Dash & Gladwin, 2007; Jasanoff, 1998; Lindell et al., 2001).

Dash and Gladwin (2007) identify risk perceptions as a key factor in evacuation decision making. However, risk perception does not always lead to a quicker response (Sorensen, 1991). Risk perception is influenced by the perceived knowledge, trustworthiness, and protective action responsibility of the government and individuals (Arlikatti, Lindell, & Prater, 2007; Lindell, Arlikatti, & Prater, 2009; Murphy, Greer, & Wu, 2018). Experience with a hazard can also change how risk is perceived and increase a person's willingness to consider and take protective action (Greer, Wu, & Murphy, 2018). In addition, Wu et al. (2015) found that participants sought information from an authoritative source to explain risk information.

Once people perceive the risk, they identify and evaluate protective actions prior to choosing to act or not (Lindell, 2018; Lindell & Perry, 2012). Protective actions can be characterized as hazard related attributes (protecting people and property) and resource related attributes (cost, time, effort, knowledge, and skills) (Lindell, 2018; Lindell et al., 2009; Lindell & Perry, 2012). Lindell et al. (2009) found that hazard adjustment attributes (protecting people and property) are judged on more than benefits and economic costs. Risk perception influences the intent to take protective action (Wu, Greer, Murphy, & Chang, 2017). However, perceiving risk does not always result in taking protective action, even when there is agreement that preparing for an earthquake is beneficial (Whitney, Lindell, & Nguyen, 2004).

Verification of the warning message, referred to as part of the "milling" process, is one of the activities that occurs during the time period between receiving a warning and taking protective action (Mileti & Sorensen, 1990a). During this time, people verify warning messages, contemplate their personal consequences, and evaluate which protective actions to take (Drabek, 1999; Sorensen & Mileti, 1988; Urbanik et al., 1980). Choices made often reflect past experiences, are made after validation and invitations to seek protective action, and are influenced by observing the choices of others (Drabek, 2013; Greer et al., 2018; Lindell & Perry, 2012).

The psychologic process is influenced by the receiver's personal characteristics, demographic attributes, past experience, and resources (Greer et al., 2018; Lindell, 2018). Lindell (2018) indicates few demographic variables directly measure people's resources; personal characteristics influence the psychologic processes in varied ways. Overall, the influence of demographic characteristics do not produce consistent patterns (Arlikatti et al., 2007; Lindell et al., 2009). While age is known to influence cognition within the PADM (Mayhorn, 2005), other demographic characteristics have not been studied

2.3.3 Behavioral Response

Once a decision is made to take protective action, implementation of that action remains. People "frequently delay implementation until they have determined that the immediacy of the threat justifies the disruption of normal activities" (Lindell & Perry, 2012, p. 623). Some people intend to act but do not initiate that action (Lindell, 2018). Response actions are influenced by the adequacy of the information provided. When information shared about the threat or recommended protective action is insufficient and time is available, people seek additional information from other sources (Lindell, 2018). Once the necessary information is available and questions answered, protective action implementation may occur (Lindell, 2018). However, access to information does not necessitate action.

Situational impediments and facilitators influence the implementation of behavioral response. Situational impediments typically override protective action initiation more so than unexpected facilitators (Lindell, 2018). For example, the lack of access to a personal vehicle impedes evacuation even when one wants to evacuate (Wu, Lindell, & Prater, 2012). Similarly, road capacity can limit evacuation of large urban areas (Kendra, Rozdilsky, & McEntire David, 2008). Research shows homeowners are more likely to evacuate, and there is evidence that education is an increasingly important indicator of predicting whether people choose to and are able to evacuate (Huang et al., 2016).

2.4 Evacuation Studies

While research on the mechanisms of dam incidents and failure is plentiful, evaluation of protective action decision making for dam failure events are limited. As such, one must look to evacuation studies for other hazard types. Most evacuation research focuses on when to evacuate (Sorensen, 1991; Sorensen & Mileti, 1988) and who does or does not evacuate (Dash & Gladwin, 2007). Quite a bit of attention has been given to hurricane evacuation (Dash & Gladwin, 2007; Dash & Morrow, 2000; Dow & Cutter, 2000, 2002; Huang et al., 2016; Whitehead, 2003; Wu et al., 2012; Wu et al., 2015).

Horney, MacDonald, Willigen, Berke, and Kaufman (2010) found that although risk perception and flood risk are correlated, neither risk perception or actual flood risk were related to evacuation decision making in Hurricane Isabel. However, in the Colorado floods of 2013, those who believed flooding would severely damage or destroy their property and those who believed the flood would injure or kill someone in their family were more likely to protect their property (Wu, Arlikatti, Prelog, & Wukich, 2017). It is unknown if the distance or time to arrival impacts risk perception or protective action taking for dam incidents.

Studies comparing the protective actions of populations of varying distance from dam incidents are also limited. Most evacuation studies focus on the distance evacuees must travel to reach their destination (Dash & Morrow, 2000; Dow & Cutter, 2000, 2002; Whitehead, 2003; Wu et al., 2012) and less on whether distance from the threat influences action. In hurricane evacuation studies, distance from the coast is related to evacuation departure time indicating that those living farther from the coast begin their evacuations later (Lindell, Kang, & Prater, 2011; O'Neill, Brereton, Shahumyan, & Clinch, 2016; Wu et al., 2012). Lindell, Lu, and Prater (2005) also found proximity to the coast and inland waterways were important environmental cues in evacuating prior to Hurricane Lili; evacuation rates decreased relative to the predicted landfall point. In a meta-analysis of hurricane evacuation studies, Huang et al. (2016) found that geographic proximity is a consistent predictor of hurricane evacuation.

Sorensen (1991) found a weak relationship between the distance from the hazard site and the time period during which warning was received, with nearer populations receiving warning earlier than those farther away. However, mobilization was similar throughout the population regardless of distance from the hazard. Mileti and Fitzpatrick (1992) studied the Parkfield earthquake using three communities that "were similar in size, and varied by earthquake experience and distance from the predicted quake's epicenter" (p. 395). The key findings were the same across all three communities regardless of distance from the event (Mileti & Fitzpatrick, 1992). Maderthaner, Guttmann, Swaton, and Otway (1978) found that persons living nearer a nuclear reactor perceived the risks to be lower than those who lived farther away at .5 km and 1.4 km; however, the closest population rated the risk the same as those who lived on average 10 km away from the reactor. Flood risk perception is lowest where floods occur frequently and infrequently, and highest where the flood frequency is in between (Burton, Kates, & White, 1968). O'Neill et al. (2016) found that the distance to the perceived flood zone does impact flood risk perception.

2.5 Summary

This literature review began by placing dams in a risk context and examined the Time Phased Model of Warning and Response (Sorensen & Mileti, 2014a, 2014b, 2014c, 2018; Urbanik et al., 1980) and the Protective Action Decision Model (Lindell, 2018; Lindell & Perry, 2012). Finally, evacuation studies were discussed.

Improved understanding of protective action decision making, and the time it takes to receive warning, decide, and initiate evacuation can reduce damage to property and life loss. It can also help dam owner and operators, emergency managers, and other officials responsible for evacuations to better understand evacuation behaviors, advance predictive modeling during risk assessments, and plan for the time necessary to initiate evacuation. Existing studies attempt to quantify warning diffusion and protective action initiation delay times, but few studies attempt to explain and predict variation in those times based on socioeconomic or sociodemographic factors, or distance. Little research exists on how these factors may influence protective action for events involving major infrastructure, such as dams. To address this issue, this study integrates the PADM (Lindell, 2018) and the Time Phased Model of Warning and Response (Sorensen & Mileti, 2018). The PADM variables will be used to test its association with warning diffusion, protective action initiation delay, and protective action initiation. A Time Phased Protective Action Decision Making Model was conceptualized and applied to data pertaining to evacuation behaviors during the 2017 Oroville event (Figure 4). Twenty (20) research questions were used to test four (4) research hypothesis about warning diffusion, and protective action initiation delay, and protective action initiation.

Warning Diffusion:

(WQ1A) Which warning receiver sociodemographic characteristics predict warning receipt time in Population A[1]?

(WQ1B) Which warning receiver sociodemographic characteristics predict warning receipt time in Population B?

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[1] Sorensen and Mileti (2018) utilize Population 1 and Population 2 to distinguish between the two sample populations.

(WH1A) People in Population A who live nearer to Oroville dam received warning before those farther away.

(WH1B) People in Population B who live nearer to Oroville dam received warning before those farther away.

Protective Action Initiation Delay

Risk Perception

(PQ1A) Do people in Population A living nearer to Oroville Dam perceive risk differently than people farther away?

(PQ1B) Do people in Population B living nearer to Oroville Dam perceive risk differently than people farther away?

(PQ2A) Do people in Population A living nearer to Oroville Dam understand the warning message differently than those farther away?

(PQ2B) Do people in Population B living nearer to Oroville Dam understand the warning message differently than those farther away?

(PQ3A) Do people in Population A living nearer to Oroville Dam believe the risks differently than those farther away?

(PQ3B) Do people in Population B living nearer to Oroville Dam believe the risks differently than those farther away?

(PQ4A) Do people in Population A living nearer to Oroville Dam report the evacuation message aided in decision making differently than those farther away?

(PQ4B) Do people in Population B living nearer to Oroville Dam report the evacuation message aided in decision making differently than those farther away?

(PQ5A) What are the correlations among Population A's message belief, risk belief, understanding, risk perception, and decision making?

(PQ5B) What are the correlations among Population B's message belief, risk belief, understanding, risk perception, and decision making?

Pre-evacuation Behaviors

(PQ6A) After first warning, how did Population A communicate with others?

(PQ6B) After first warning, how did Population B communicate with others?

(PQ7A) From where did Population A seek additional information?

(PQ7B) From where did Population B seek additional information?

(PQ8A) What actions did people in Population A take after being warned and before evacuation?

(PQ8B) What actions did people in Population B take after being warned and before evacuation?

Protective Action Initiation

(EH1A) Message believability, risk belief, risk perception, understanding, decision making, distance, warning receipt time, and sociodemographic characteristics predict whether people in Population A evacuated.

(EH1B) Message believability, risk belief, risk perception, understanding, decision making, distance, warning receipt time, and sociodemographic characteristics predict whether people in Population B evacuated.

(EQ1A) Do additional pre-evacuation messages, message believability, warning receipt time, risk belief, understanding, risk perception, decision making, distance, and socioeconomic considerations predict protective action initiation time in Population A?

(EQ1B) Do additional pre-evacuation messages, message believability, warning receipt time, risk belief, understanding, risk perception, decision making, distance, and socioeconomic considerations predict protective action initiation time in Population B?

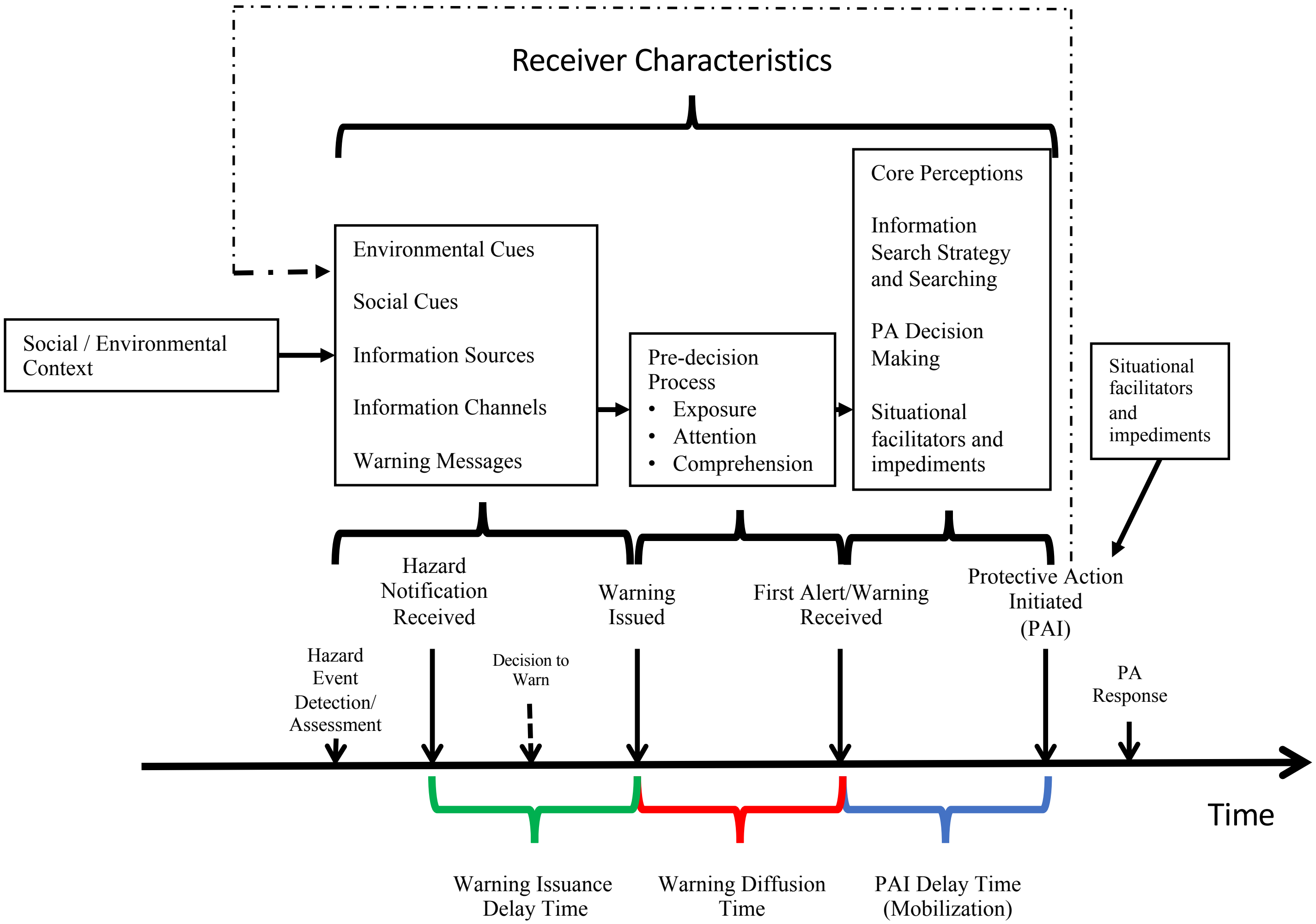

Figure 4. Time Phased Protective Action Decision Making Model

CHAPTER III

METHODOLOGY

3.1 Data Collection

This study makes use of the survey data that was collected by Drs. Sorensen and Mileti. Drs. Sorensen and Mileti were under contract with the United States Army Corps of Engineers (USACE) to collect data on warning and evacuation related to the Oroville Dam incident (Sorensen & Mileti, 2018). The questionnaire was comprised of primarily closed ended (multiple choice and Likert scale) questions with opportunities to provide additional information for an "other" selection, as well as fill in the blank questions regarding time. Drs. Sorensen and Mileti hired the Social Science Research Center (SSRC) at California State University Fullerton to collect and code data from the downstream population. This study will make use of the downstream population survey data for Butte County (Population A) and Sutter and Yuba Counties (Population B). The data is available upon request from the USACE.

The primary purpose for the data collection was to "determine if new warning technologies available in the nation today require changes to the issuance, diffusion, and protective action initiation curves previously recommended to the USACE for use in dam and levee failure loss of life estimation models" (Sorensen & Mileti, 2018, p. 1). However, in addition to the data on warning technologies, the questionnaire collected empirical data on the warning decision process, timing of protective action implementation, and the ways in which people implemented protective action. Sociodemographic information was also collected.

3.2 Sample Selection and Method

Two separate and distinct populations were surveyed – Population A comprised of Butte County closest to Oroville Dam, and Population B comprised of people from Sutter and Yuba County (Sorensen & Mileti, 2018). The sample was derived using addresses within block groups that were partially or completely in the study area (i.e. downstream of the Oroville dam); however, nearly 85% of the sample block groups had the entirety of the households within the study area (Sorensen & Mileti, 2018). A total of 5,000 addresses were randomly selected for inclusion (2,500 for Population A and 2,500 for Population B) and mailed the questionnaire and cover letter with non-completers receiving a reminder postcard (Sorensen & Mileti, 2018). Figure 5 identifies the households selected by Drs. Sorensen and Mileti (2018) for inclusion in the sample.

The completion rate for Population A (Butte County) was 17.4% with 435 people returning the survey and a sampling fraction of 1% (Sorensen & Mileti, 2018). The margin of error for the Population A sample is reported as ±2.32 points at the 95% confidence level (Sorensen & Mileti, 2018). The completion rate for Population B (Sutter and Yuba Counties) was 16% with 400 people completing the survey (Sorensen & Mileti, 2018). The margin of error for the Population B sample is reported as ±2.45 points at the 95% confidence level, and the sampling fraction for Population B is 0.3% (Sorensen & Mileti, 2018). The different sampling fractions for Population A and Population B prevent combining the data for analysis in this study. When the study sample was compared to the American Community Survey 5-year estimates from the 2012-2016 period, biases were detected in the sample with respect to race, income level, and level of education (Sorensen & Mileti, 2018).

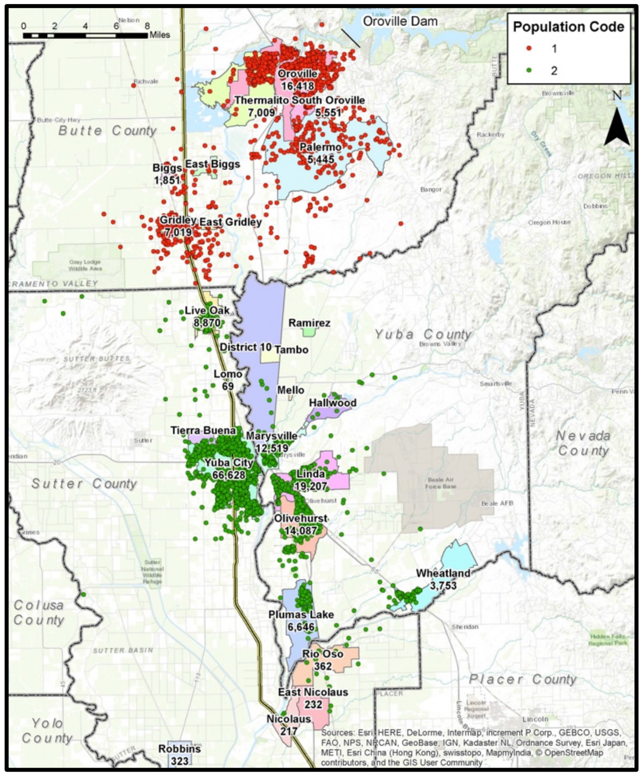

Figure 5. Households selected for inclusion in the sampling frames

Source: Sorensen and Mileti (2018)

3.3 Measures

Utilizing the data described collected by Sorensen and Mileti (2018), this study utilizes multiple variables to measure the factors that best explain warning diffusion, protective action initiation delay time, and protective action initiation. The variables for this analysis include the personal characteristics collected in the survey (age, education, income, gender, ethnicity, occupation, role/responsibility), as well as distance, warning receipt time, message believability, risk belief, risk perception, information searching channel, information searching source, pre-evacuation actions, understanding, protective action initiation delay time, and protective action initiation.

3.3.1 Variables

<u>*Personal / Sociodemographic Characteristics*</u>. The dataset includes self-reported information on gender (*male, female, other*), ethnicity (*White, Hispanic or Latino, Black or African American, Asian, Native Hawaiian or Other Pacific Islander, American Indian or Alaskan Native, Other*),

age (*18-24 years, 25-34 years, 35-44 years, 45-54 years, 55-64 years, 65-74 years, 75 years and older*), education (*Less than High school diploma, High school diploma or equivalent, some college but no degree, Associate degree, Bachelor degree, Graduate degree*), income (*Less than $15,000, $15,000-$24,999, $25,000-$34,999, $35,000-$49,999, $50,000-$74,999, $75,000-$99,999, $100,000-$149,999, $150,000-$199,999, $200,000 or more*), occupation (*employed (including self-employed), working 1-39 hours per week; employed (including self-employed), working 40 or more hours per week; not employed, looking for work; not employed, not looking for work; retired; disabled, not able to work; and stay at home mom/dad*), and role/responsibility (*children under age of 18, adults over the age of 18 and under the age of 65, adults age 65 and older, pets*). The descriptive statistics for the sociodemographic variables are in Chapter 4. The dataset codes for gender were transformed for 1 to indicate female and 0 to indicate male or other, and the dataset for ethnicity was transformed for 1 to indicate white and 0 to consolidate Hispanic or Latino, black or African America, Asian, Native Hawaiian or Other Pacific Islander, American Indian or Alaskan Native, and other responses. The occupation responses were recoded as 1 for employed, including self-employed, and 0 for all others. The responses to the questions regarding number of children, adults, and pets living in the household were summed to give a total responsibility number.

Distance. Distance was categorized as near and far for both Population A and Population B. In Population A, the near population includes Oroville, South Oroville, East Oroville, Palermo, and Thermalito. The far Population A includes East Biggs, Gridley City, and East Gridley. In Population B, near is defined as Yuba City, Live Oak, Tierra Buena, Marysville, Hallwood, and District 10. Far is defined as Nicholas, Rio Oso, Linda, Olivehurst, Plumas Lake, and Wheatland.

Warning Receipt Time. Warning receipt time was the time the respondent reported receiving the warning. The date and time were converted to a continuous variable with t_0 equal to midnight on

February 12. Those who received warning prior to February 12 were excluded from any analysis using warning receipt time.

Message Believability. Message believability measures the extent to which the respondent believed the first evacuation message with 1 representing "not at all believable," and 6 representing "completely believable."

Risk Belief. Risk belief is measured three ways using a Likert scale with 1 representing "did not believe," and 6 representing "fully believed." The measurement assessed the extent to which respondents believed the emergency spillway would break, their home would flood, and/or their town will flood. A Risk Belief Index was created by calculating the mean of the three measurements.

Understanding. Understanding measures how well the respondents understood each of the seven measurement items (what could happen at the dam; risk of flooding; what actions to take; which locations could be affected; when to evacuate; how long to stay away; and who the message was from). A Likert scale was used to assess each measure with 1 representing "did not understand at all," and 6 representing "fully understood." An Understanding Index was created by calculating the mean of the seven measurements.

Risk Perception. Risk perception was measured five different ways on a Likert scale from 1 to 6, with 1 representing "not likely," and 6 representing "extremely likely." The questions assessed include the following: the message was meant for me, I might become injured, other people might become injured, I might die, or other people might die. Each respondent's answers were combined into a Risk Perception Index that consists of the mean of the five responses.

Decision Making. Decision-making was measured four different ways using a Likert scale with 1 indicating "disagree," and 6 indicating "agree." The measures were in response to the following:

message helped me decide what to do, it was easy to decide what to do, I was able to decide what to do quickly, or I decided what to do with confidence. The mean of the responses make up the Decision Making Index.

Information Searching Channel. Information searching channel measures which methods of communication were used between the receipt of the first evacuation message and the time in which the respondent began to evacuate or decided not to evacuate. Seven choices were given: face-to-face conversation, land line phone call, cell phone call, cell phone text message, social media such as Facebook or Twitter, other, or I did not communicate with others. Respondents were asked to identify all channels that applied. Each option is coded as 1 for selected and 0 for not selected.

Information Searching Source. Information searching source measures information seeking behavior sources between the first evacuation message and the time the respondent began the evacuation or decided not to evacuate. Seven options were given: friends, relatives, neighbors, co-workers; local officials such as fire, sheriff, or police; state officials such as the Department of Water Resources, CAL Fire, or Office of Emergency Services; internet/website; social media, for example, Facebook or Twitter; other; and I did not seek additional information. The questionnaire allowed for multiple responses, and each source was coded as 1 for selected and 0 for not selected.

Pre-evacuation Actions. Pre-evacuation actions measures whether or not the respondent completed any of the nine options listed after receiving warning and before evacuating or deciding not to evacuate. The actions offered were: reunite with family members; reunite or attend to pets; secure my home; secure my business; pack items to take with me; told others I was going/where I was going; helped others get ready to evacuate; other; and I didn't do anything before evacuating. Respondents were allowed to identify multiple actions, and each action was coded as a 1 for selected and 0 for not selected.

Protective Action Initiation. Protective action initiation is measured by whether or not the respondent evacuated. The variable was coded 1 for evacuate and 0 for did not evacuate.

Protective Action Initiation Delay Time. Protective Action Initiation Time measures the date and time the respondent began to evacuate. The questionnaire collected this information in two questions, one for the date of evacuation, and one for the time in hours and minutes after midnight on the day indicated in date response. The time in hours and minutes was coded as minutes after midnight on the day indicated on the day of evacuation. In order to create a consistent time variable, the date and time were recoded to a continuous variable, with t_0 as midnight on Sunday, February 12. Those who reported evacuating prior to February 12 were excluded from any analysis of protective action initiation delay time.

3.4 Analytical Methods

Four statistical tests were used in this study: linear regression, logistic regression, independent samples t-tests, and analysis of variance (ANOVA). Chronbach's alpha will be used to test the reliability of the risk belief, understanding, risk perception, and decision-making indices.

Appendix 1 identifies the variables and statistical tests for each of the research questions and research hypothesis. Research questions WQ1A, WQ1B, EQ1A, and EQ1B will use linear regression. An independent sample t-test will be used for research hypothesis WH1A and WH1B and research questions PQ1A, PQ1B, PQ2A, PQ2B, PQ3A, PQ3B, PQ4A, and PQ4B. Protective action initiation hypothesis EH1A and EH1B were tested using logistic regression. Research questions PQ5A and PQ5B will be tested using correlation, and PQ6A, PQ6B, PQ7A, PQ7B, PQ8A, and PQ8B will be tested using repeated measure ANOVA.

CHAPTER IV

RESULTS

4.1 Descriptive Statistics

The dataset includes self-reported information on age, education, income, sex/gender, ethnicity, occupation, and role/responsibility for both Population A and Population B. Comparisons are made to the American Community Survey 5-year estimates from the 2012-2016 period for some variables by Sorensen and Mileti (2018). Females make up 49.8% of Population A compared to 49.1% male (n=422). A little over 1% of Population A indicated other, and thirteen did not provide a gender. In Population B, females comprised 47.4% of respondents, and men were 52.6% of the respondents (n=390). Ten people in Population B did not indicate their gender.

Table 1. Gender of Respondents

	Percent in Population A	Percent in Population B
Male	49.052	52.564
Female	49.763	47.436
Other	1.185	0.000
Total	100.000	100.000

Populations A (83.3%) and Population B (75.4%) identified primarily as white, which is higher than the percent of white persons in sampled area population (Sorensen & Mileti, 2018). There were fewer Hispanic or Latino and Asian persons in the sample populations than in the sampled area (Sorensen & Mileti, 2018). In Population A, thirteen respondents did not indicate their gender and eleven did not indicate a race. Ten respondents did not indicate their gender and nine did not indicate a race/ethnicity in Population B.

Table 2. Race/Ethnicity of Respondents*

	Population A		Population B	
	Percent in Sample	Percent in Population	Percent in Sample	Percent in Population
White	83.255	59.700	75.448	49.000
Hispanic or Latino	8.491	23.100	10.486	30.300
Black or African American	1.179	2.100	2.302	2.400
Asian	1.887	8.300	5.627	12.400
Native Hawaiian or Other Pacific Islander	0.236	0.200	0.767	0.400
American Indian or Alaskan Native	3.302	1.200	1.790	0.800
Other	1.651	6.400	3.581	2.700
Total	100.000	100.0	100.000	100.000

* Adapted from John H. Sorensen and Mileti (2018)

The reported education levels of the respondents over age 25 were higher than those of population (Table 3) (Sorensen and Mileti, 2018). Sorensen and Mileti (2018) reported that of the Population A respondents over age 25, 10.2% had less than a high school diploma, whereas the total population with less than a high school diploma is 34.5%. Slightly more people in Population A reported graduate degrees (7.2%) compared to the population (5%). Five respondents were under age 25 in Population A. Eleven respondents in Population A did not report an age and were excluded from the statistic. An additional seventeen persons did not report an income level.

Sorensen and Mileti (2018) reported that of the Population B respondents over the age of 25, 5.9% had less than a high school diploma compared to 36.2% of the population. In addition, 67.1% of Population B had a high school diploma or equivalent (compared to 36.4% in the population), and 11.1% had a graduate degree (compared to 8.4%) (Sorensen and Mileti, 2018). Eight respondents in Population B were under age 25. Six respondents did not report an age and were excluded from the statistic. An additional twenty-one persons did not report a level of education and were also excluded.

Table 3. Education of Respondents Age 25 or Higher*

	Population A		Population B	
	Percent in Sample	Percent in Population	Percent in Sample	Percent in Population
Less than a high school diploma	10.199	34.500	5.930	36.200
High school diploma or equivalent	23.881		16.442	
Some college but no degree	33.582	47.200	32.075	36.400
Associates Degree	10.945		18.598	
Bachelor Degree	14.179	13.300	15.903	19.000
Graduate Degree	7.214	5.000	11.051	8.400
Total	100.000	100.000	100.000	100.000

* Adapted from John H. Sorensen and Mileti (2018)

Sorensen and Mileti (2018) also found the median household income of respondents in Population A ($25,000 to $34,999) to be slightly lower than the averaged median income of the block groups in the sampled area ($39,049). Population B's median income ($50,000 to $74,999) is higher than the mean of the median household incomes of each block group ($39,049) (Sorensen and Mileti, 2018). Fifty-six respondents did not provide income data in Population A, and twenty-eight respondents did not provide income data in Population B. Table 4 shows the income distribution of the respondents with the median income values in bold text.

Table 5 presents the reported age distribution of respondents. The median age value of 5 for both Population A and Population B corresponds to 55-64 years of age (bolded in Table 3). Eleven respondents did not report an age in Population A, and six respondents did not report an age in Population B.

Table 4. Income of Respondents*

	Population A		Population B	
	Percent in Sample	Cumulative Percent	Percent in Sample	Cumulative Percent
Less than $15,000	17.678	17.678	9.140	9.140
$15,000 - $24,999	18.206	35.884	8.602	17.742
$25,000 - $34,999	15.303	51.187	13.441	31.183
$35,000 - $49,999	13.720	64.908	13.441	44.624
$50,000 - $74,999	16.623	81.530	19.892	64.516
$75,000 - $99,999	6.596	88.127	13.172	77.688
$100,000 - $149,999	5.805	93.931	13.441	91.129
$150,000 - $199,999	3.694	97.625	5.376	96.505
$200,000 or more	2.375	100.000	3.495	100.000
Total	100.000		100.000	
No response	56		28	

* Adapted from Sorensen and Mileti (2018).

Table 5. Age of Respondents

	Percent in Population A	Percent in Population B
18-24 years old	1.179	2.030
25-34 years old	8.491	7.868
35-44 years old	10.849	9.137
45-54 years old	17.925	17.513
55-64 years old	25.943	27.411
65-74 years old	20.283	21.066
75 years or older	15.330	14.975
Total	100.000	100.000

Table 6 presents the employment status of respondents for Population A and Population B. Slightly less than half of the respondents in Population A are employed (46.1%), whereas most respondents in Population B are employed (51.4%). Approximately 30% of both Population A (29.5%) and Population B (30.9%) are retired, and 18.1% of Population A and 12.8% of Population B are disabled and unable to work.

Table 6. Employment Status of Respondents

	Percent in Population A	Percent in Population B
Employed (incl self-employed), working 1-39 hours/week	19.048	15.601
Employed (incl self-employed), working 40 or more hours/week	27.143	35.806
Not employed, looking for work	2.857	1.535
Not employed, not looking for work	1.429	1.023
Retired	29.524	30.946
Disabled, not able to work	18.095	12.788
Stay at home mom/dad	1.905	2.302
Total	100.000	100.000

On the day the evacuation order was issued, the median number of persons living in the household for both Population A and Population B was 2. The mean number of persons living in the household was 2.69 in Population A and 2.79 in Population B. The maximum number reported was twenty for both Population A and Population B. Twelve respondents did not provide a response on household size in Population A, and thirteen did not in Population B. The mean number of children under the age of 18 was 0.89 in Population A and 0.83 in Population B. The median value for both populations was zero. The mean number of persons age 65 or older in respondent households was 0.93 in Population A and 0.92 in Population B, with a median of 1 in both sample populations. The mean number of pets present was 3.47 in Population A and 2.2 in Population B, with a median value of 2 in Population A and 1 in Population B.

In Population A, most of the people (82.1%) live in the near population, defined in Section 3.3.1 as Oroville, South Oroville, East Oroville, Palermo, and Thermalito. The remainder resided in East Biggs, Gridley City, and East Gridley, all of which are farther from the dam. In Population B, 71.6% of the population live in the near population, and 28.4% comprise the far population. The near population of Population B resides in Yuba City, Live Oak, Tierra Buena, Marysville, Hallwood, and District 10, whereas the far population resides in Nicholas, Rio Oso, Linda, Olivehurst, Plumas Lake, and Wheatland. Table 7 shows the breakdown of the near and far sub-populations of each sample population. Respondents who selected "other" as their residence city were not assigned a sub-population of near or far for either Population A or Population B.

Table 7. Near and Far Population Totals

	Population A		Population B	
	Frequency	Percent	Frequency	Percent
Near	321	82.097	270	71.618
Far	70	17.903	107	28.382
Total		100.000		100.000

Protective action was measured by the question "Did you evacuate?" In Population A, 68.2% of the respondents evacuated, whereas 31.8% did not. A larger percent of Population A's far sub-population evacuated than the population near the dam. In Population B, 68.9% evacuated and 31.1% did not. A larger percentage of the near sub-population evacuated than the far. Seven respondents did not provide an answer in Population A, and ten respondents did not provide an answer in Population B. Table 8 shows the evacuation results for Population A and Population B broken out by the near and far sub-populations.

Table 8. Evacuation

	Population A			Population B		
	Percent Evacuate	Percent Did Not Evacuate	Percent Total	Percent Evacuate	Percent Did Not Evacuate	Percent Total
Near	65.506	34.494	100.000	70.076	29.924	100.000
Far	80.882	19.118	100.000	66.019	33.980	100.000
Total	68.229	31.771	100.000	68.937	31.063	100.000

* Adapted from Sorensen and Mileti (2018).

4.2 Index Reliability

Understanding, risk belief, risk perception, and decision making included multiple measurements in the survey; an index was created for each (Table 9). Understanding was measured as how well the respondent understood each of the seven measures related to flooding (what could happen at the dam; flood risk; what actions to take; which locations could be affected; when to evacuate;

how long to stay away; who the message was from), with 1 indicating "did not understand at all," and 6 indicating "fully understood." The Understanding Index has a *Chronbach's* α= .879 for Population A (M=4.220) and .892 for Population B (M=4.301), indicating the questionnaire achieved an acceptable level of reliability. A mean above the midrange (3-4) indicates the respondents moderately understood the message, what could happen at Oroville dam, and what actions to take. However, the mean value indicates there is also room to improve the understanding of the potentially impacted public.

Whether or not respondents believed the message (risk belief) was measured three different ways (the spillway would break, my home would flood, my town would flood). The resulting risk belief index has a mean of 4.139 for Population A and 4.080 for Population B, with 1 indicating "not at all believable," and 6 indicating "completely believable." The index mean is slightly higher than the midrange (3-4) indicating the respondents moderately believed the spillway would break and flooding would occur. The *Cronbach's alpha* (*Chronbach's* α= .838 for Population A and *Chronbach's* α=.886 for Population B) showed the questionnaire reached an acceptable level of reliability.

Five measurements (the message was meant for me, I might become injured, other people might become injured, I might die, or other people might die) represent risk perception after receiving the first evacuation message, with 1 indicating "not likely," and 6 indicating "extremely likely." The measurements were combined into an index (Population A *Chronbach's* α= .861and Population B *Chronbach's* α=.908) with a resulting mean of 3.916 for Population A and 3.968 for Population B, indicating that respondents perceived moderate risk to property or people. The questionnaire reached an acceptable level of reliability.

Decision-making was measured four different ways (the message helped me decide what to do, it was easy to decide what to do, I was able to decide what to do quickly, or I decided what to do with confidence), with 1 indicating "disagree," and 6 indicating "agree." The resulting decision-making index has a mean of 4.368 for Population A and 4.445 for Population B. Mean values above the mid-range indicate the message to evacuate helped in deciding, deciding was easy and quick, and the respondents were confident in deciding. The *Cronbach's alpha* (Population A *Chronbach's* α= .898; Population B *Chronbach's* α=.908) showed the questionnaire reached an acceptable level of reliability.

Table 9. Index Statistics

	Index	N	Minimum	Maximum	Mean	Standard Deviation	Cronbach's α
Population A	Understanding	357	3.028	4.655	4.220	9.578	.879
	Risk belief	363	3.507	4.499	4.139	4.563	.838
	Risk perception	363	2.909	4.636	3.916	7.437	.861
	Decision-making	365	4.268	4.449	4.368	6.384	.898
Population B	Understanding	338	3.101	4.695	4.301	9.374	.892
	Risk belief	353	3.773	4.450	4.080	4.674	.886
	Risk perception	345	2.890	4.658	3.968	7.056	.857
	Decision-making	349	4.344	4.521	4.445	6.171	.908

4.3 Addressing the Research Questions and Hypothesis

4.3.1 Warning Diffusion

Linear regression was used to answer research questions (WQ) 1A (*Which warning receiver sociodemographic characteristics predict warning receipt time in Population A?)* and WQ1B (*Which warning receiver sociodemographic characteristics predict warning receipt time in the Population B)*. Table 10 shows the results of the linear regression. The results indicate that age, education, and income explain 3.3% of the variance in the time it took to receive warning in

Population B. Income is a significant predictor of warning receipt time in Population B. Age and education were not a significant predictor of warning receipt time in either population. The model results for Population A were not significant.

Table 10. Regression Analysis Warning Receipt

Model	Population A (WQ1A)	Population B (WQ1B)
(Constant)	1147.754	1169.884
Age	-5.683	18.881
Education	-35.741*	-19.169
Income	3.143	-21.890*
	$F_{(3)}$=1.466 p=.224 $Adj.\ R^2$ = .005	$F_{(3)}$=4.205 p=.008* $Adj.\ R^2$ = .033

*The statistic is significant at the p<.05 level.

Table 11. Independent-Samples T-Test Warning Receipt Time versus Distance

	Distance									
	Near			Far			95% CI for Mean			
	M	SD	n	M	SD	n	Difference	t	df	p
Population A Warning Receipt Time	1009.40	357.174	240	1025.29	317.425	51	-122.303, 90.507	-.294	289	.769
Population B Warning Receipt Time	1053.97	344.780	200	1108.63	426.143	83	-149.849, 40.563	-1.130	281	.259

Independent-samples t-tests were used to test research hypothesis (WH) 1A (*People in Population A who live nearer to Oroville Dam receive warning before those farther away.*) and WH1B (*People in Population B who live nearer to Oroville Dam receive warning before those farther away.*). Table 11 demonstrates the results of independent-samples t-tests when comparing the time (minutes) of reported warning receipt (warning receipt time) of those nearer to, and farther from Oroville dam in both Population A and Population B. The results were not significant for Population A or Population B.

4.3.2 Protective Action Initiation Delay

Independent-samples t-tests were used to test risk perception research question 1A (PQ1) (*Do people in Population A living nearer to Oroville Dam perceive risk differently than people farther away?*) and PQ1B (*Do people in Population B living nearer to Oroville Dam perceive risk differently than people farther away?*). The test compared the risk perception index for those nearer and farther from Oroville Dam (Table 12). The results indicate there was not a significant difference in risk perception of those nearer to Oroville Dam or farther away in Population A or Population B.

Table 12. Independent-Samples T-Test – Risk Perception Index versus Distance

	Distance									
	Near			Far			95% CI for Mean Difference	t	df	p
	M	SD	n	M	SD	n				
Population A Risk Perception Index	3.989	1.481	278	3.824	1.542	62	-.247, .577	.787	338	.432
Population B Risk Perception Index	3.940	1.453	243	4.054	1.277	99	-.449, .222	-.666	340	.506

To answer PQ2A (*Do people in Population A living nearer to Oroville Dam understand the warning message differently than those farther way?*) and PQ2B (*Do people in Population B living nearer to Oroville Dam understand the warning message differently than those farther* *way?*) independent-samples t-tests were used to compare the understand index means, to distance (Table 13). There was not a significant difference in understanding of those nearer to Oroville Dam compared to those farther away in Population A or Population B.

Table 13. Independent-Samples T-Test -- Understanding Index versus Distance

	Distance									
	Near			Far			95% CI for Mean Difference	t	df	p
	M	SD	n	M	SD	n				
Population A Understanding Index	4.291	1.262	281	4.088	1.470	62	-.178, .585	1.050	341	.294
Population B Understanding Index	4.252	1.348	245	4.405	1.325	99	-.467, .161	-.958	342	.339

Independent samples t-tests were also used to test PQ3A (*Do people in Population A living nearer to Oroville dam believe the risks could materialize differently than those farther away?*) and PQ3B (*Do people in Population B living nearer to Oroville dam believe the risks could materialize differently than those farther away?*), comparing the risk belief index with distance. There was a significant difference in mean risk belief of those nearer to Oroville Dam compared to those farther away in Population A. People who live closer to the dam in Population A had a greater mean belief that the risk could materialize than those farther away (Near M= 4.254, *SD*= 1.482; Far M=3.725, *SD*=1.808; $t_{(342)}$=2.455, *p*=.015). The means were not significantly different in Population B.

Table 14. Independent Samples T-Test - Risk Belief versus Distance

	Distance									
	Near			Far			95% CI for Mean			
	M	SD	n	M	SD	n	Difference	t	df	p
Population A Risk Belief Index	4.254	1.482	281	3.725	1.808	63	.105, .953	2.265*	81.6	.033
Population B Risk Belief Index	4.094	1.572	245	4.040	1.572	99	-.315, .422	.286	342	.775

* p<.05

PQ4A (*Do people in Population A living nearer to Oroville Dam report the evacuation message aided in decision making differently than those farther away?*) and PQ4B (*Do people in Population B living nearer to Oroville Dam report the evacuation message aided in decision making differently than those farther away?*), compare distance with the decision-making index. There was not a significant difference in the decision making of those nearer to Oroville Dam compared to those farther away in Population A or Population B. The results are shown in (Table 15).

Table 15. Independent Samples T-Test -- Decision-Making Index

	Distance									
	Near			Far			95% CI for Mean Difference	t	df	p
	M	SD	n	M	SD	n				
Population A Decision-making Index	4.421	1.571	279	4.153	1.689	62	-.172, .708	1.198	339	.232
Population B Decision-making Index	4.384	1.550	243	4.587	1.489	98	-.574, .148	-1.162	339	.246

Correlation analysis was used to answer PQ5A (*What are the correlations among Population1's message belief, risk belief, understanding, risk perception, and decision-making?*). The results are presented in Table 16. Believability of the evacuation message (message belief) is positively correlated with risk belief (r=.454, p<.01), understanding (r=.433, p<.01), risk perception (r=.418, p<.01), and decision-making (r=.338, p<.01) in Population A.

Table 16. Correlations Between Message Belief, Risk Belief, Understanding, Risk Perception, and Decision-Making in Population A

	1	2	3	4	5
1. Message Belief	-				
2. Risk Belief Index	.454**	-			
3. Understand Index	.433**	.330**	-		
4. Risk Perception Index	.418**	.642**	.317**	-	
5. Decision-Making Index	.338**	.229**	.567**	.272**	-

** Correlation is significant at the 0.01 level (2-tailed).

Correlation analysis was also used to answer PQ5B (*What are the correlations among Population B's message belief, risk belief, understanding, risk perception, and decision-making?*). The results are presented in Table 17. Believability of the evacuation message (message belief) is positively correlated with risk belief (r=.515, p<.01), understanding (r=.399, p<.01), risk perception (r=.450, p<.01), and decision-making (r=.375, p<.01) in Population B.

Table 17. Correlations Between Message Belief, Risk Belief, Understanding, Risk Perception, and Decision-Making in Population B

	1	2	3	4	5
1. Message Belief	-				
2. Risk Belief Index	.515**	-			
3. Understand Index	.399**	.416**	-		
4. Risk Perception Index	.450**	.591**	.333**	-	
5. Decision-Making Index	.375**	.359**	.593**	.294**	-

** Correlation is significant at the 0.01 level (2-tailed).

Repeated-measure ANOVA was used to answer PQ6A (*After first warning, how did Population A seek information?*) and PQ6B (*After first warning, how did Population B communicate with others?*). In Population A (*Wilks' Lambda* = .462; $F_{(6, 429)}$=92.916, p<.01) and Population B (*Wilks' Lambda* = .427; $F_{(6, 394)}$=113.657, p<.01), the channels used are significantly different across groups. Cell phone call, face-to-face, conversation, and cell phone text messages were the most popular channels in Population A and in Population B. Table 18 shows the means of each channel by population.

Repeated measure ANOVA was also used to answer PQ7A (*From which sources did Population A seek additional information?*) and PQ7B (*From which sources did Population B seek additional information?*). The information source used are significantly different across groups in Population A (*Wilks' Lambda* = .500; $F_{(6, 429)}$=74.411, p<.01) and Population B (*Wilks' Lambda* = .550; $F_{(6, 394)}$=53.739, p<.01),. In both Population A and in Population B, respondents sought information from friends, relatives, neighbors, and co-workers more than any other source.

Table 18. Information Searching Channel

	Population A (N= 435)		Population B (N=400)	
	M	S.D.	M	S.D.
1. Face-to-Face Conversation	.315	.465	.360	.481
2. Land Line Phone Call	.211	.409	.210	.408
3. Cell Phone Call	.552	.498	.605	.489
4. Cell Phone Text Message	.290	.454	.380	.486
5. Social Media	.140	.348	.127	.334
6. Other	.028	.164	.035	.184
7. Did Not Communicate with Others	.080	.272	.060	.238
	Wilks' Lambda =.462 $F_{(6,429)}$=92.916 *p<.01*		*Wilks' Lambda* =.427 $F_{(6,394)}$=113.657 *p<.01*	

Table 19. Information Searching Source

	Population A (N= 435)		Population B (N=400)	
	M	S.D.	M	S.D.
1. Friends, Relatives, Neighbors, Co-workers	.494	.501	.532	.500
2. Local Officials	.103	.305	.133	.339
3. State Officials	.053	.224	.107	.310
4. Internet - Website	.147	.355	.168	.374
5. Social Media	.168	.374	.147	.355
6. Other	.108	.311	.105	.307
7. Did Not Seek Additional Information	.225	.418	.208	.406
	Wilks' Lambda =.500 $F_{(6,429)}$=74.411 *p<.01*		*Wilks' Lambda* =.550 $F_{(6,394)}$=53.739 *p<.01*	

PQ8A (*What actions did Population A take after being warned and before evacuation or deciding not to evacuate?*) and PQ8B (*What actions did Population B take after being warned and before evacuation or deciding not to evacuate?*) were also analyzed using repeated measure ANOVA. In both Population A (*Wilks' Lambda* = .414; $F_{(8, 427)}$=745.693, *p*<.01) and Population B (*Wilks'*

Lambda = .322; $F_{(8, 392)}$=102.973, *p*<.01), pre-evacuation actions varied significantly across action type. Population A and Population B packed items to take with during the evacuation and secured their homes.

Table 20. Pre-evacuation Actions

	Population A (N= 435)		Population B (N=400)	
	M	S.D.	M	S.D.
1. Reunite with Family Members	.329	.470	.315	.465
2. Reunite or Attend to Pets	.262	.440	.303	.460
3. Secure My Home	.409	.492	.523	.500
4. Secure My Business	.025	.157	.028	.164
5. Pack Items to Take With Me	.584	.493	.668	.472
6. Told Other I Was Going/Where I Was Going	.356	.479	.422	.495
7. Helped Others Get Ready to Evacuate	.175	.380.	.175	.380
8. Other	.080	.272	.050	.218
7. Did Not Do Anything Before Evacuating	.080	.272	.078	.268
	Wilks' Lambda =.414 $F_{(8,427)}$ =745.693 *p<.01*		*Wilks' Lambda* =.322 $F_{(8,392)}$ =102.973 *p<.01*	

4.3.3 Protective Action Initiation

A logistic regression was used to test protective action initiation hypotheses 1A (EH1A) (*Message believability, risk belief, risk perception, understanding, decision-making, distance, warning receipt time, and sociodemographic characteristics predict whether people in Population A evacuated.*). The logistic regression model is statistically significant ($X^2_{(14)}$=66.369, *p*<.01), and the results are shown in Table 21. In Population A, the model explained 37.1% of the variance in the dependent variable – evacuation (*Nagelkerke* R^2=.371) – and correctly classified 82.8% of the evacuations. Risk belief, risk perception, decision making, distance, income, and warning receipt time are significant predictors of evacuation. For every unit increase in risk belief (*Wald*=5.000, *df*=1, *p*<.05), the likelihood of evacuation increases 1.48 times after controlling for the other variables in the model. For each unit increase in risk perception (*Wald*=4.267, *df*=1, *p<.05*), the likelihood of evacuation increases 1.477 times. Evacuation likelihood increases 1.402 times for each unit increase in the decision-making index (*Wald*=4.604, *df*=1, *p*=<.05). For each unit nearer to the dam (*Wald*=8.811, *df*=1, *p*=<.01), evacuation likelihood increases 6.117 times. Each unit increase in income (*Wald*=7.159, *df*=1, *p*=<.01) results in a .763 increase in evacuation likelihood. Finally, as warning receipt time (*Wald*=5.447, *df*=1, *p*=<.05) increases, the likelihood of evacuation increases .999, indicating later warning receipt decreases evacuation likelihood. Had the warning receipt time been measured in hours, a more meaningful result might become evident.

Table 21. Logistic Regression Population A

	Wald	df	ρ	Exp(β)
Message Believability	1.380	1	0.240	0.849
Risk Belief Index	5.000	1	0.025*	1.480
Understand Index	3.353	1	0.067	0.691
Risk Perception Index	4.267	1	0.039*	1.477
Decision-making Index	4.604	1	0.032*	1.402
Distance (Near)	8.811	1	0.003**	6.117
Female	1.865	1	0.172	1.650
White	0.441	1	0.506	1.387
Employed	0.000	1	0.991	0.995
Responsibility	0.013	1	0.911	0.999
Age	2.323	1	0.127	0.802
Education	0.010	1	0.921	1.015
Income	7.159	1	0.007**	0.763
Warning Receipt Time	5.447	1	0.020*	0.999
Constant	1.223	1	0.269	4.378

* The regression coefficient is significant at the <.05 level.
** The regression coefficient is significant at the <.01 level.

A logistic regression was used to test EH1B (*Message believability, risk belief, risk perception, understanding, decision-making, distance, warning receipt time, and sociodemographic* *characteristics predict whether people in Population B evacuated*.) The logistic regression model is statistically significant ($X^2_{(14)}$=37.633, p<.01), and the results are shown in (Table 22). In Population B, the model explained 21.7% of the variance in the dependent variable – evacuation (*Nagelkerke* R^2=.217) – and correctly classified 74.1% of evacuations. Message believability, decision-making, and race (white) are significant predictors of evacuation. For every unit increase in message believability (*Wald*=64.343, *df*=1, p<.05), the likelihood of evacuation increases 1.312 times, after controlling for other variables in the model. Similarly, for each unit increase in the decision-making index (*Wald*=10.293, *df*=1, p<.01), the likelihood of evacuation increases 1.543 times. White people were .425 times more likely to evacuate (*Wald*=3.981, *df*=1, p<.05).

Table 22. Logistic Regression Population B

	Wald	df	ρ	Exp(β)
Message Believability	4.343	1	0.037*	1.312
Risk Belief Index	0.004	1	0.952	0.992
Understand Index	2.740	1	0.098	0.765
Risk Perception Index	0.042	1	0.838	1.032
Decision-making Index	10.293	1	0.001**	1.543
Distance (Far)	2.220	1	0.136	0.590
Female	0.401	1	0.526	1.234
White	3.981	1	0.046*	0.425
Employed	0.461	1	0.497	0.772
Responsibility	0.031	1	0.861	0.993
Age	1.984	1	0.159	0.838
Education	3.633	1	0.057	1.300
Income	0.683	1	0.409	0.921
Warning Receipt Time	1.413	1	0.235	0.999
Constant	0.201	1	0.654	1.790

* The regression coefficient is significant at the <.05 level.
** The regression coefficient is significant at the <.01 level.

Linear regression was used to answer research questions EQ1A (*Does message believability, warning receipt time, risk belief, understanding, risk perception, decision making, distance, and socioeconomic considerations predict protective action initiation time in Population A?*) and EQ1B (*Does message believability, warning receipt time, risk belief, understanding, risk perception, decision making, distance, and socioeconomic considerations predict protective action initiation time in Population B*). The results (

Table *23*) indicate warning receipt time (t=4.684, *p*<.01) is the only significant predictor of protective action initiation time in Population A. Warning receipt time (*t*=8.078, *p*<.01), message believability (*t*=-2.010, *p*=<.05), and income (*t*=-43.074, *p*<.05) are significant predictors of protective action initiation time in Population B.

Table 23. Regression Analysis – Protective Action (Evacuation) Initiation Time

Model	Protective action (evacuation) time: Population A	Protective action (evacuation) time: Population B
(Constant)	496.419	1084.86
Warning Receipt Time	0.588**	0.766**
Message Believability	19.058	-53.805*
Risk Belief Index	6.91	2.864
Understanding Index	46.48	-9.04
Risk Perception Index	-26.52	20.881
Decision Making Index	-28.704	-20.964
Distance	57.099	-58.493
Age	-3.969	12.058
Education	-13.38	6.971
Income	-26.273	-43.074*
Gender (Female)	-10.534	-30.725
Race (White)	18.218	-89.589
Employed	63.195	1.102
Responsibility	-0.316	1.166
	$F_{(14)}=2.303$ $p= .007$** Adj. $R^2=.100$	$F_{(14)}=7.462$ $p= .000$** Adj. $R^2=.357$

* The regression coefficient is significant at the <.05 level.
** The regression coefficient is significant at the <.01 level.

CHAPTER V

DISCUSSION

The purpose of this research was to understand protective action decision making in a slow onset dam incident and to test which variables can predict warning diffusion, and protective action initiation delay, and protective action initiation (evacuation). Analysis of the data collected revealed some new findings, while also supporting and refuting previous studies. This chapter discusses in detail the results from Chapter 4.

5.1 Warning Diffusion

Government issued warnings facilitate evacuation for many people (Drabek, 2013; Huang et al., 2016). Understanding how warning moves through a population (warning diffusion), including who is warned and when, can increase the number of people warned. Population A and Population B were both divided into a near and far sub-population to evaluate the impact of distance from the event center on warning diffusion. Results of WH1A and WH1B, testing whether warning receipt time varied by distance for each population, were not significant, indicating there is not a relationship between distance (near and far populations) and mean warning time in Population A or in Population B. Sorensen (1991) found a weak relationship between the distance from the hazard site and when warning was received, with nearer populations receiving warning earlier than those farther away. The results are also inconsistent with additional research on distance (Lindell, 2018; Mileti & Sorensen, 1990; Sorensen, 1991); however, the slow speed of the onset of the event or the unofficial warnings that began approximately a week prior to the first official warning (Sorensen & Mileti, 2018) could explain why the results were not significant. The subconscious exposure and comprehension of the pre-warning messages related to the ongoing incident at Oroville Dam and the time that passed between the incident and data collection may have led to some households not recalling the warning, or inaccurately recalling their first warning (Lindell, 2018; Lindell & Perry, 2012; Sorensen & Mileti, 2018; Wu et al., 2015). In addition, in Population A, the sample contained households that were not at risk, which may result in warning message time recall failure. The lack of difference may also be explained by the lack of data on each structure's distance from the dam, error in the reported times due to the amount of time that had passed from the event until the survey was administered, or by the lack of responses from households farthest from the dam in Population B. Finally, identifying the sample of Population A was hindered by the message indicating that "low lying" areas should evacuate, so the sample likely over-represents people who were not at risk and may not recall receiving warning (Sorensen & Mileti, 2018).

Analysis of which sociodemographic characteristics predict warning receipt time for Population A (WQ1A) and Population B (WQ1B) did not produce significant results in Population A, but income predicted warning receipt time in Population B. The results for Population A indicate that income, age, and education are not predictors of when warning will be received and other variables may be influencing warning receipt time. Income predicted warning receipt time in Population B. Population B's median income is higher than that of the overall population, which should indicate better access to evacuation information overall; however, technologies, frequency of warning, informal notifications, where people were, and what they were doing might better predict the time in which warning was first received. The results augment past findings where older people were less likely to hear a warning, and those of high socioeconomic status are more likely to hear a warning (Sorensen, 1991). Sorensen and Mileti (2018) examine technologies, frequency of warning, informal notifications, where people were, and what they were doing, all of which might better predict the time in which warning was first received.

5.2 Protective Action Initiation Delay

Mileti and Sorensen (1990) describe the warning response process of hearing, understanding, believing, personalizing, deciding and responding, and confirming as an ordered-choice process, even if it is not linear for everyone. Hearing the alert or warning was covered in the prior section. The following tests assess the remaining portions of the warning response process.

PQ2A and PQ2B tested whether understanding varied for the near and far sub-populations for both Population A (PQ2A) and Population B (PQ2B). Understanding was measured with seven questions on the survey, each measured on a Likert scale of 1 (did not understand at all), to 6 (fully understood). The questions assessed what could happen at the dam, risk of flooding, what to do, what locations would be affected, when to evacuate, how long to stay away, and who the message was from. It should be noted that "understanding does not refer to correct interpretation of what is heard, but rather to the personal attachment of meaning to the message" (Dennis S Mileti & Sorensen, 1990a, pp. 5-2). However, when the understand matrix is combined, it does measure an understanding of the risks associated with the Oroville Dam incident. Neither Population A's near and far populations (PQ2A), nor Population B's near and far populations (PQ2B), had significantly different means, indicating that understanding did not vary significantly by distance.

The risk belief index measured whether respondents believed the spillway would break, their home would flood, and their town would flood, with 1 indicating "did not believe," and 6 indicating "fully believed." The questions reflect personal risk, which is thought to be necessary for initiating protective action (Huang et al., 2016; Mileti & Sorensen, 1990; Sorensen, 1991; Sorensen, 2000). In Population A (PQ3A), the near sub-population and far sub-population had significantly different risk belief means, with the near population having a greater risk belief mean (M=4.254) than the far population (M= 3.725). This suggests that risk belief varies by distance. However, the results were not significant in Population B (PQ3B). The lack of responses from households farthest from the dam may influence this result.

Results of prior studies on flood risk and risk perception have produced mixed results, and the same was true for this research. Results of PQ1A and PQ1B tested whether risk perception was different in the near and far populations of Population A (PQ1A) and Population B (PQ1B). Risk perception was measured five different ways, each with a Likert scale with 1 indicating "not likely," and 6 indicating "extremely likely." The tests were not significant, indicating risk perception did not vary based on distance from Oroville Dam. This is consistent with conclusions from O'Neill et al. (2016) that distance to a perceived flood zone does not impact flood risk perception. Maderthaner et al. (1978) found that persons living nearer to a nuclear reactor perceived the risks lower than those who lived farther away at .5km and 1.4km, but those living on average 10km away from the reactor rated the risks the same as those living close. The distances within both Population A and Population B may be significant enough to produce a similar result; however, additional location data would be necessary to determine if that is true.

The decision-making index reflects the mean of four questions related to decision-making in the survey: the message helped me decide what to do, it was easy to decide what to do, I was able to decide what to do quickly, and I decided what to do with confidence. Each was measured on a Likert scale of 1 (disagree) to 6 (agree). Neither Population A (PQ4A), nor Population B (PQ4B) produced significant results when comparing the means between the near and far populations. This might be explained by the amount of time available for the population to decide, the slow onset of the dam incident, or the time lag between the incident and data collection.

PQ5A and PQ5B examined correlations between the message belief, risk belief index, understand index, risk perception index, and decision-making index. The correlation tests whether the steps of the warning process are related to one another. In Population A (PQ5A), the findings demonstrate that message belief is moderately correlated with risk belief, understanding, risk perception, and decision making. Each index is also correlated to the others: risk belief and risk perception showed a strong positive correlation. The remaining indices are moderately correlated. Population B's results (PQ5B) also showed a moderate positive correlation between message belief and the indices. The indices were also moderately correlated.

The risk belief, understand, risk perception, and decision-making warning response process described by Mileti and Sorensen (1990b) is predicated on a believable warning message. Increases in message belief are thought to increase risk perception and personal risk belief (Lindell, 2018; Mileti & Sorensen, 1990), therein motivating evacuation behaviors. This suggests that efforts to increase belief in messages would increase risk perception. However, Horney et al. (2010) found that while risk perception and flood risk are correlated, neither risk perception or actual flood risk were related to evacuation decision making in Hurricane Isabel, which indicates a more complex relationship between risk perception and taking protective action. For example, O'Neill et al. (2016) found that the distance to the perceived flood zone does impact flood risk perception. The results of this study provide empirical evidence of a correlation between message belief and the warning decision process for a slow onset dam incident.

Mileti and Sorensen (1990b) describe confirmation of the warning message as ongoing throughout the warning response process and influencing the other aspects of the process. When warning messages do not contain all the information people want or need, they seek additional information (Lindell, 2018; Lindell & Perry, 2012; Mileti & Sorensen, 1990b; Rogers & Sorensen, 1988). The results indicate that information searching did occur during the Oroville Dam incident after the first warning message was received and before initiating protective action or deciding not to take protective action, and that the information seeking varies significantly by source. In Population A, 55% of the population responded that they sought information via a cell phone call, followed by 31% from a face-to-face conversation, whereas social media was the lowest used information channel. Population B sought information primarily through a cell phone call (60%), cell phone text message (38%), and face-to-face conversation (36%). Social media was also the lowest used channel (13%) in Population B. The information searching source most utilized in both Population A and B was through personal interaction with a friend, relative, neighbor, or coworker (Population A 49% and Population B 53%). Nearly a quarter of Population A and a fifth of Population B did not seek additional information.

In addition to seeking additional information, protective action initiation was delayed while people took additional actions to prepare for evacuation. Here, too, the results varied significantly by action in both Population A and Population B. In Population A, 58% of the population took time to pack items to take with them, 41% secured their home, 36% informed others they were evacuating, and 33% reunited with family members. In Population B, 67% took time to pack items to take with them, 52% secured their home, and 42% told others where they were going.

5.3 Protective Action Initiation

In hurricane evacuation studies, distance from the coast is related to evacuation departure time indicating that those living farther from the coast begin their evacuations later (Lindell et al., 2011; O'Neill et al., 2016; Wu et al., 2012). Lindell et al. (2005) also found proximity to the coast and inland waterways were important environmental cues in evacuating prior to Hurricane Lili and evacuation rates decreased relative to the predicted landfall point. The tests in this section examine the relationship between message believability, risk belief, understanding, risk perception, decision making, distance, warning receipt time, and sociodemographic characteristics and protective action.

PH1A and PH1B hypothesized that message believability, risk belief, understanding, risk perception, decision-making, distance, warning receipt time, and sociodemographic characteristics predict whether people in Population A (PH1A) and Population B (PH1B) took protective action (evacuated). The model explained approximately 37% of the variance in Population A's evacuating behavior and 21.7% in Population B. Risk belief, risk perception, decision making, distance, income, and warning receipt time were significant predictors of evacuation in Population A. Message believability, decision making, and race were significant predictors of evacuation in Population B.

The results of PQ2A and PQ2B tested whether message believability, warning receipt time, risk belief, understanding, risk perception, decision making, distance, and socioeconomic considerations predict protective action initiation time in Population A (PQ2A) and Population B (PQ2B). In Population A, warning receipt time predicts protective action initiation time. In Population B, warning receipt time, message believability, and income were predictors of protective action initiation time. Dash and Gladwin (2007) identify risk perceptions as a key factor in evacuation decision making, but Sorensen (1991) found the level of risk perception does not always lead to a quicker response. That was the case at Oroville Dam as well.

The warning response process should culminate in taking protective action (Mileti and Sorensen, 1990). In Population A, the risk belief, risk perception, and decision-making indices were a significant predictor of evacuation, indicating that the personalization and perception of risk and decision making motivate evacuation. However, none of the indices predicted the time in which protective action would be initiated in Population A, indicating that the warning response process is important for deciding whether or not to evacuate, but perhaps less predictive of when people will initiate evacuation. Population A's result are consistent with past research, indicating that whether a message is believed or understood is less important than the personalization of the risk (Mileti & Sorensen, 1990).

Increases in warning receipt time in Population A decreased the likelihood of evacuation and increased the protective action initiation time. This indicates that those who receive warning later are less likely to evacuate, and receiving warning later delays the initiation of the evacuation. Those living near the dam in Population A were six times more likely to evacuate than those farther from Oroville Dam. Past research indicates those nearest the hazard are more likely to evacuate (Lindell et al., 2011; Lindell et al., 2005; Mileti & Sorensen, 1990a; O'Neill et al., 2016; Sorensen & Mileti, 1988; Wu et al., 2012), and those farther from a hazard evacuate after those nearer (Wu et al., 2012).

Income was also a significant predictor of evacuation in Population A, but not protective action initiation time. The results indicate that increases in income decrease the likelihood of evacuation, which is inconsistent with past results based on other hazard types where those who have the means to evacuate, as indicated by higher incomes, are more likely to do so (Mileti & Sorensen, 1990). This might be explained by the fact that Population A likely over-represents people who were not at risk.

In Population B, unit increase in message belief increases the odds of evacuation by 31% and decreases the protective action initiation time. Message belief could reflect the quality of the message provided for Population B, which would be consistent with past findings (Mileti & Sorensen, 1990); however, there is not enough information in the model to determine why message belief was a significant predictor for evacuation behavior. The decision-making index shows a 54% increase in evacuation, but did not predict protective action initiation time. The lack of significance of risk belief and risk perception is inconsistent with past results and the conceptual models of Lindell and Perry (2012), Lindell (2018), and Mileti and Sorensen (1990b).

In Population B, as warning receipt time increases, so did the protective action initiation time indicating those warned later also evacuated later. This trend was similar with those with higher incomes. This suggests that the “milling process,” including message verification, contemplating personal consequences, and evaluating protective action options, took place (Drabek, 1999; Mileti & Sorensen, 1990b; Sorensen & Mileti, 1988; Urbanik et al., 1980). Taking longer to evacuate, but being clear in the decision (decision making index) suggests that people had time to contemplate their decision and then initiate evacuation. This might not be the case in a quick onset dam failure event

CHAPTER VI

CONCLUSION

Though the bodies of literature available on evacuation behavior and on mechanisms of dam incidents and failure are voluminous, the infrequent occurrence of incidents involving dams limits the amount of research available on evacuation and protective action decision making for such incidents. This research sought to improve understanding of evacuation behaviors around dam incidents. Ultimately, the research could aid in improved predictive models, and help those responsible for warning the public with their decisions, ultimately reducing fatalities should a dam fail. This study utilized data collected by Drs. Mileti and Sorensen (2018) to consider evacuation notice and response during the 2017 Oroville Dam incident. A combined twenty research questions and four research hypotheses were tested by applying quantitative methods to survey data for Population A and Population B. This chapter discusses the resulting conclusions, implications for practice, study limitations, and opportunities for further research.

6.1 Warning Diffusion and Protective Action Initiation

Infrastructure, including dams, will continue to play an important role in water resource development; however, dams do not completely eliminate flood risk and their presence introduces an additional risk to the public. When risks are introduced, human behaviors are influenced, impacting how and when individuals take protective action, such as moving out of harm's way in the face of a dam incident. Understanding and estimating warning diffusion, protective action initiation time, and protective action initiation related to dams can save people's lives.

Government issued warnings facilitate evacuation for many people (Drabek, 2013; Huang et al., 2016). Mileti and Sorensen (1990b) describe a warning response process of hearing, understanding, believing, personalizing, deciding and responding, and confirming the warning message. Warning receipt time did not vary by distance in this study, but that may be due to subconscious exposure and comprehension of the pre-warning messages related to the risks, which may have led to some households not recalling the warning, or inaccurately recalling their first warning (Lindell, 2018; Lindell & Perry, 2012; Sorensen & Mileti, 2018; Wu et al., 2015). Research has demonstrated that demographic characteristics do not always produce consistent patterns (Arlikatti et al., 2007; Lindell et al., 2009), which was also the case in this study.

Distance did not provide statistically significant differences in understanding, risk perception, or decision-making for either Population A or Population B in this study. Risk belief of the near population in Population A was higher than that of the far population; however, mean risk belief was not significantly different in Population B. This may be because of the construct of the distance variable and the need to keep Population A and Population B analysis separate from one another due to different rates of inclusion in the study sample. However, message belief and understanding, risk belief, risk perception, and decision-making were correlated, indicating that there is a relationship between belief in the warning message and the personalization of risks during the Oroville Dam incident. Increases in message belief are thought to increase risk perception and personal risk belief (Lindell, 2018; Mileti & Sorensen, 1990), which motivate evacuation behaviors suggesting that efforts to increase belief in messages would increase risk personalization.

The process of confirming the warning message was evident in the Oroville Dam incident, as people in Population A and Population B sought additional information. For both populations, the information seeking varies significantly by channel and source. In addition to seeking additional information, protective action initiation was delayed while people took additional actions to prepare for evacuation, indicating that preparedness for an event, or lead time to prepare, could reduce the overall time to take protective action.

The warning response process should culminate in taking protective action (Mileti and Sorensen, 1990), which is why protective action and protective action initiation time were evaluated. Risk belief, risk perception, decision making, distance, income, and warning receipt time were significant predictors of evacuation in Population A, and warning receipt time was a predictor of protective action initiation time. Message believability, decision making, and race were significant predictors of evacuation in Population B, and warning receipt time, message believability, and income were predictors of protective action initiation time. This is consistent with Mileti and Sorensen (1990), and it also indicates consistency with Lindell and Perry (2012) in that people delay protective action until the threat is immediate. Warning receipt time is significant for both evacuating and the protective action initiation time in Population A. This is important for dam owners and operators, as well as warning officials, to know as a delay in issuing warning results in a delay in receiving warning, which then will delay evacuation even in a slow developing dam incident.

6.2 Time Phased Protective Action Decision Making Model

The Protective Action Decision Model does not attempt to associate time or time estimates within the model, yet each of the sub-components of the information flow overlap the contributing factors of the Time Phased Model of Warning and Evacuation. This study begins to bring together the PADM and Time Phased Model of Warning and Evacuation. Figure 4 conceptually links the communication flow of the PADM with the time frames presented in the Time Phased Model of Warning and Evacuation.

The characteristics of the evacuation notice receiver were tested for their impacts on warning diffusion, protective action initiation, and protective action initiation time. Income predicted warning receipt time and protective action initiation time in Population B. Income predicted evacuation in Population A and race predicted evacuation in Population B. This suggests that personal characteristics may be related to warning diffusion time and protective action initiation time, but like past studies, the relationship varies and is inconsistent.

The psychological processes of the PADM were separated in order to better represent the timeframes in which the processes take place. The pre-decisional processes are aligned with the warning diffusion time, the core perceptions and information strategy, and searching with protective action initiation delay time. Pre-decisional processes will impact whether and when a warning message is received, thereby initiating the remainder of the decision-making process. Delays in receiving warning are reflected in the warning diffusion time.

Delays in taking protective action are influenced by core perceptions, information searching, decision-making, and situational facilitators and impediments. Core perceptions were measured by the warning response process of understanding, risk belief, risk perception, and decision-making in this study, including whether they varied by distance in Population A or Population B. The results were mixed, but perhaps a function of the distance data available. Mean risk belief was higher in the population living nearer to the dam in Population A, suggesting risk belief varies by distance. Examination of the correlations between believability of the first evacuation message (message belief), understanding, risk belief, risk perception, and decision-making showed a strong positive correlation between risk belief and risk perception in Population A. Risk belief and decision-making predicted evacuation in Population A, and message believability and decision-making predicted evacuation in Population B. Message believability also predicted protective action initiation time in Population B. Taken together, this suggests that core perceptions do influence protective action initiation and protective action initiation time.

Information searching and the information strategy were combined, because the behavior response of seeking information and the psychological process of the information strategy likely delay protective action initiation time. Both Population A and Population B reported seeking information via a cell phone call and through personal interaction with a friend, relative, neighbor, or coworker. In addition, both populations took time to prepare to evacuate by packing items to take with them and securing their homes.

Warning receipt time predicted protective action initiation time in Population A and Population B, which suggests that issuing warning and the pre-decisional processes have a significant impact on when people evacuate. Message believability also predicted protective action initiation time in Population B. Risk belief, risk perception, and decision-making predicted evacuation in Population A, and message believability and decision-making predicted evacuation in Population B. This suggests that core perceptions and information searching may not delay evacuation, but the decision to evacuate is influenced by at least some aspects of core perception processes and information searching.

Like all conceptual models, this one comes with its limitations. The process by which people decide to take protective action is not linear and does not use all aspects of the PADM. In addition, not all warning comes from an official source, lending the hazard detection and warning issuance delay time to overlapping iterations with warning diffusion. Model adjustments may be necessary to account for the speed of onset of a hazard and for low probability, high consequence events that may not fit the model as conceptualized.

6.3 Practical Implications and Recommendations

There are many practical implications of this research for emergency managers, infrastructure owners, and federal government decision making. This is one of the few studies that evaluates research questions and hypotheses for protective action decision making for a dam incident, including the delays in protective action initiation. In addition, it is one of the only studies on protective action decision making utilizing empirical data from a dam incident, and one of the only studies that uses distance in the decision-making process and timing of evacuation analysis. This study also offers an opportunity to demonstrate what people do between warning and evacuation. The study also provides insight into how people processed the warning message, and in turn understood, believed, perceived, and decided what to do about the risks. This portion of the psychological process provides insight to whether and how urgently people initiated protective action. Improved understanding of household decision making allows infrastructure owner and operators, emergency managers, and other government officials responsible for evacuations to better understand evacuation behaviors, advance predictive modeling during risk assessments, and plan for the time necessary to initiate evacuation.

Federal government agencies utilize predictive life loss models that incorporate anticipated human behavior to inform decisions on characterizing, reducing, and managing risks associated with dams and for flood risk in general. The modeling is used to characterize the risks posed by infrastructure should anything go wrong with the facility, to make multi-million-dollar decisions to reduce risks, and to manage the remaining risk. The decisions include whether dams meet federal tolerable risk guidelines, what risk remains once dams and other infrastructure are in place, and whether to build (or not) infrastructure at all. Improving the accuracy of the modeling, as well as identifying factors that may not be currently accounted for in the modeling, allows for a more informed risk characterization, risk reduction recommendation, and emergency planning.

The federal government, however, cannot prevent all life loss through improvements to infrastructure performance; therefore, an improved understanding of human behavior also facilitates a shared responsibility between the government and those who benefit from the infrastructure. The improved understanding can be used to advise emergency managers and government officials, as well as the population living in at-risk areas. Improved understanding of human behavior in response to risk information is also used to inform emergency action plans that indicate who to notify when an infrastructure problem is detected and evacuation planning. Given the uncertainty of when a flood fight, including intervention in a dam incident, will become a hazard, early warning with clear messaging can save people's lives.

The results of this study can also help demonstrate the value of issuing timely warning messages, which was shown to impact protective action initiation time. Understanding what people do between receiving an evacuation message and taking protective action can help emergency managers and warning officials identify ways to encourage at risk population preparedness, including producing information in the channels and sources most utilized by people. It also gives a more realistic expectation of what people will do once warning is issued, rather than assuming people will immediately begin evacuating when the risk is not imminent. The study also provides insight into how people processed the warning message, and in turn understood, believed, perceived, and decided what to do about the risks. Finally, emergency managers can utilize the information to encourage awareness of infrastructure and its benefits and risks so when protective action becomes necessary, the infrastructure and its role are not a surprise to people at risk.

6.4 Study Limitations and Opportunities for Further Research

This study, like all studies of human behavior, has its limitations. The data for the study were collected nine months after the Oroville Dam incident. This impacted the quality of some of the data in the study. For example, respondents identified evacuation days and times that occurred prior to the official warning at rates higher than likely would have occurred if the data were collected closer to the Oroville Dam incident. In addition, the Population A sample was hard to identify due to the warning telling low lying areas to evacuate, and sampling the whole county likely lead to over-representation of people not at risk (J. H. Sorensen & Mileti, 2018). The samples of Population A and Population B could not be combined due to different sampling methodologies for each population, and the dataset lacked geocoded locations, both of which limited analysis of distance to dichotomous near/far. A continuous measure of distance may have produced more significant results. This study did not have access to the warning issuance delay data, which could have improved the understanding of the events leading up to the warning issuance and Time Phased Protective Action Decision Model. Future research should include the impact of distance on protective action decision making, collect and analyze additional receiver characteristic variables related to each step of the protective action decision making process, and seek to understanding the warning issuance process.

The Time Phased Protective Action Decision Making Model needs further refinement and testing, including any delays in detecting a hazard and its impact on warning issuance and protective action decision-making. The time it takes to move from hazard detection to protective action completion also needs additional study. The impact of the hazard characteristics on decision-making and protective action initiation timing also would improve understanding of protective action decision making. The results of the Oroville Dam incident may not materialize in other events due to the long duration onset, heightened awareness, and near miss nature of the Oroville Dam incident. Research should continue to seek ways to predict and understand warning diffusion, protective action initiation delay, and protective action initiation for more urban areas, and a variety of extreme events including a rapid onset, high urgency events involving infrastructure failure.

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APPENDIX A – STATISTICAL TESTS

Warning Diffusion Research Questions and Hypothesis

RQ/ RH #	**RQ/RH**	**Question/ Hypothesis**	**Independent Variable**	**Dependent Variable**	**Test**
WQ1A	Which warning receiver sociodemographic characteristics predict warning receipt time in Population A?	Question	Age, Education, Income	Warning Receipt Time	Linear regression
WQ1B	Which warning receiver sociodemographic characteristics predict warning receipt time in Population B?	Question	Age, Education, Income	Warning Receipt Time	Linear regression
WH1A	People in Population A who live nearer to Oroville Dam received warning before those farther away.	Hypothesis	Distance	Warning Receipt Time	Independent-Samples T-test
WH1B	People in Population B who lived nearer to Oroville dam received warning before those farther away.	Hypothesis	Distance	Warning Receipt Time	Independent-Samples T-test

Protective Action Initiation Delay Research Questions

RQ/ RH #	RQ/RH	Question/ Hypothesis	Independent Variable	Dependent Variable	Test
PQ1A	Do people in Population A living nearer to Oroville Dam perceive risk differently than people farther away?	Question	Distance	Risk Perception Index	Independent-Samples T-test; Cronbach's alpha
PQ1B	Do people in Population B living nearer to Oroville Dam perceive risk differently than people farther away?	Question	Distance	Risk Perception Index	Independent-Samples T-test; Cronbach's alpha
PQ2A	Do people in Population A living nearer to Oroville Dam understand the warning message differently than those farther way?	Question	Distance	Understanding Index	Independent-Samples T-test; Cronbach's alpha
PQ2B	Do people in Population B living nearer to Oroville Dam understand the warning message differently than those farther way?	Question	Distance	Understanding Index	Independent-Samples T-test; Cronbach's alpha
PQ3A	Do people in Population A living nearer to Oroville dam believe the risks could materialize differently than those farther away?	Question	Distance	Risk Belief Index	Independent-Samples T-test; Cronbach's alpha
PQ3B	Do people in Population B living nearer to Oroville dam believe the risks could materialize differently than those farther away?	Question	Distance	Risk Belief Index	Independent-Samples T-test; Cronbach's alpha

RQ/ RH #	RQ/RH	Question/ Hypothesis	Independent Variable	Dependent Variable	Test
PQ4A	Do people in Population A living nearer to Oroville Dam report the evacuation message aided in decision making differently than those farther away.	Question	Distance	Decision Making Index	Independent-Samples T-test; Cronbach's alpha
PQ4B	Do people in Population B living nearer to Oroville Dam report the evacuation message aided in decision making differently than those farther away.	Question	Distance	Decision Making Index	Independent-Samples T-test; Cronbach's alpha
PQ5A	What are the correlations among Population A's message belief, risk belief, understanding, risk perception, and decision-making?	Question	Message Belief, Risk Belief Index, Risk Understanding Index, Risk perception Index, Decision-Making Index	Not Applicable	Correlation
PQ5B	What are the correlations among Population B's message belief, risk belief, understanding, risk perception, and decision-making?	Question	Message Belief, Risk Belief Index, Risk Understanding Index, Risk perception Index, Decision-Making Index	Not Applicable	Correlation
PQ6A	After first warning, how did Population A communicate with others?	Question	Information Searching Channel	Not Applicable	ANOVA

RQ/ RH #	RQ/RH	Question/ Hypothesis	Independent Variable	Dependent Variable	Test
PQ6B	After first warning, how did Population B communicate with others?	Question	Information Searching Channel	Not Applicable	ANOVA
PQ7A	From which sources did Population A seek additional information?	Question	Information Searching Source	Not Applicable	ANOVA
PQ7B	From which sources did Population B seek additional information?	Question	Information Searching Source	Not Applicable	ANOVA
PQ8A	What actions did people in Population A take after being warned and before evacuation or deciding not to evacuate?	Question	Pre-evacuation Actions	Not Applicable	ANOVA
PQ8B	What actions did people in Population B take after being warned and before evacuation or deciding not to evacuate?	Question	Pre-evacuation Actions	Not Applicable	ANOVA

Protective Action Initiation Research Questions

RQ/ RH #	RQ/RH	Question/ Hypothesis	Independent Variable	Dependent Variable	Test
EH1A	Message believability, risk belief, risk perception, understanding, decision-making, distance, and sociodemographic characteristics predict whether people in Population A evacuated.	Hypothesis	Message believability, risk belief, risk perception, understanding, decision-making, responsibility, race, distance, income, age, sex, education, employed	Evacuation	Logistical Regression
EH1B	Message believability, risk belief, risk perception, understanding, decision-making, distance, and sociodemographic characteristics predict whether people in Population B evacuated.	Hypothesis	Message believability, risk belief, risk perception, understanding, decision-making, responsibility, race, distance, income, age, sex, education, employed	Evacuation	Logistical Regression
EQ1A	Do additional pre-evacuation messages, message believability, warning receipt time, risk belief, understanding, risk perception, decision making, distance, and socioeconomic considerations predict protective action initiation time in Population A?	Question	additional pre-evacuation messages, message believability, risk belief, understanding, risk perception, decision making, distance, income, age, sex, education, employed, responsibility	Protective Action Time	Linear Regression

RQ/ RH #	RQ/RH	Question/ Hypothesis	Independent Variable	Dependent Variable	Test
EQ1B	Do additional pre-evacuation messages, message believability, warning receipt time, risk belief, understanding, risk perception, decision making, distance, and socioeconomic considerations predict protective action initiation time in Population B?	Question	additional pre-evacuation messages, message believability, risk belief, understanding, risk perception, decision making, distance, income, age, sex, education, employed, responsibility	Protective Action Time	Linear Regression

VITA

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