WARNING ISSUANCE, DIFFUSION AND PUBLIC PROTECTIVE ACTION INITIATION DURING THE FEBRUARY 2017 OROVILLE DAM EVENT

Final Report

March 30, 2018

WARNING ISSUANCE, DIFFUSION AND PUBLIC PROTECTIVE ACTION INITIATION DURING THE FEBRUARY 2017 OROVILLE DAM EVENT

Final Report

March 30, 2018

John H. Sorensen, Ph.D.
Distinguished Research Staff, Oakridge National Laboratory, Retired
and
Dennis S. Mileti, Ph.D.
Professor Emeritus, University of Colorado Boulder

With contributions from:
Gregory L. Richards, P.E., CFM
Associate, Gannett Fleming, Inc.
and
Jesse M. Pope, E.I.T., CFM
Hydrologic and Hydraulic Designer, Gannett Fleming, Inc.

Prepared for:
U.S. Army Corps of Engineers
Risk Management Center
Davis, California

Contract No. W912QR-16-D-0002
Gannett Fleming Project No. 61106

ACKNOWLEDGEMENTS

We are indebted to a number of people and organizations for their support and assistance in the performance of this study. First and foremost, we acknowledge Jason Needham and the U.S. Army Corps of Engineers (USACE) Risk Management Center for initiating and funding this study. Jason recognized the need to better understand warning delay, especially in light of recent technological advances in public warning dissemination, and was the driving force. He also provided invaluable support and guidance to us throughout the course of the study.

We appreciate project managers Jim James and Brian Greene of Gannett Fleming for their work in managing the contractual requirements over the course of this effort. We also appreciate the efforts of Jesse Pope and Greg Richards of Gannett Fleming for their help in the day-to-day tasks of completing reconnaissance, pretesting and revising the interview schedule, pretesting and helping to revise the public questionnaire, collecting data from emergency managers, and writing this final report.

The participation of the communities impacted by the Oroville Dam event was vital to the success of this study. We are indebted to Butte County Sheriff Kory Honea, Sutter County Sheriff Paul Parker, and Yuba County Sheriff Steven Durfor who took the time to talk to us about their experiences, shared invaluable information related to warning issuance and diffusion during the event, and encouraged residents within their jurisdictions to participate in our public survey. We also appreciate the many individuals from the California Department of Water Resources (DWR) and the Federal Energy Regulatory Commission (FERC) who sat down with us and shared their insights about how the event unfolded.

We recognize the important role that the Social Science Research Center (SSRC) at California State University Fullerton played in collecting sample survey data. Specifically, we appreciate the efforts of Laura Gil-Trejo, Frederick Rose, and Lizette Sanchez in helping us to define the populations, selecting a representative sample of households, administrating the mailing and receipt of the questionnaires, coding data, quality control, creating a database for analysis, and assisting us with preliminary data analysis.

Finally, we are very grateful for the thorough peer review and excellent feedback provided by Eve Gruntfest, Ph.D. as well as other individuals from the USACE Risk Management Center. Their comments have greatly enhanced the overall content and findings summarized in this report.

EXECUTIVE SUMMARY

This study of the Oroville Dam event is the first comprehensive study of warning diffusion and protective action initiation conducted on an event where a large range of warning channels including modern warning technologies were utilized. We believe it is the only scientific study done on public response to a protective action warning concerning a possible failure of a major dam in the United States. Furthermore, it is one of the few studies to have collected statistically representative data on two study populations, differentiated by their distance from the source of the threat. All three factors make this study both unique and valuable.

Research Purpose

The primary purpose of this study was to determine if the use of modern warning technologies warrants revision of the diffusion and protective action initiation curves previously recommended to the U.S. Army Corps of Engineers (USACE) for use in dam and levee failure loss of life estimation models. Secondary purposes were to investigate the decision-making process leading to the issuance of a first public warning and obtain new empirical data on the timing of warning receipt and public protective action implementation.

Event Studied

The Oroville Dam event that occurred in February 2017 was selected for study because:

- It was a contemporary event that included the use of modern warning dissemination technologies.
- It involved public warning and protective action recommendations for a large population of people at risk due to a potential failure of the emergency spillway at one of the largest dams/reservoirs in the United States. This type of event does not happen frequently.
- The flood did not happen, which meant that the members of the public who received an evacuation message were not displaced and were readily available for study.

Key Topics Examined

The study explored the following three topics in depth:

- Issuance time which is 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 a first public warning,
- Diffusion time or the time between the point that the local authority initiates the dissemination of the first alert through the time until the entire at-risk population has received a first alert, and
- Protective action initiation (PAI) time defined as the period between receiving the first alert or warning and initiating the protective action by the public.

Three counties were selected for study since all three were evacuated during this event. These were Butte County which is closest to the dam, and Sutter and Yuba Counties which are further downstream from the dam. Including these counties in the study enabled us to compare findings while accounting for the variable of distance from the dam.

Research Methods

The study began by collecting reconnaissance information about the event and the involved counties. Information was gathered from the internet, a community windshield survey where we explored study community characteristics, and through conversations with key informants including local, state, and federal officials. This reconnaissance effort informed the development of the interview schedule and public survey questionnaire.

Two data collection methods were used to collect data on issuance, diffusion, and protective action initiation. First, we collected information regarding warning issuance from first public warning originators in each county that was studied using face-to-face interviews followed by callbacks to gather additional details. These data were analyzed qualitatively and converted into a quantitative data set for future use by the USACE. Second, we gathered data regarding warning diffusion and public protective action initiation by using a structured questionnaire mailed to a representative statistical sample of respondents in two populations. These were Butte County residents (Population 1) and the combined residents of Sutter and Yuba Counties (Population 2). These public data were quantitatively coded, a data set was produced, and the data were quantitatively analyzed and used for curve development. The findings from our data analyses and recommendations for future research and subsequent analyses follow.

Research Findings

Implications for Delay Curves. The data and analyses provided partial validation of curves developed in previous research. Our analysis provided strong support for modeling diffusion and PAI time following an official first warning over a short timeframe. However, we could not adequately model warning receipt or PAI before the official first warning was disseminated. The reporting of message receipt and PAI prior to official warnings in both populations was likely due to several factors such as pre-official warning risk information, recall error, normative bias, and anchoring (see Section 4.6.2). Consideration should be given to developing additional curves to represent longer duration events or events in which risk information is provided to the public for an extended period of time prior to the first official public warning.

The Impact of Distance. Our comparison of Population 1 in the jurisdiction adjacent to the dam (Butte County) to Population 2 in jurisdictions located further downstream (Sutter and Yuba Counties) was to assess if distance from the dam had an impact on outcomes regarding issuance, diffusion, and PAI. First, the issuance delay was shorter for Butte County than Sutter and Yuba Counties. Second, warning diffusion curves were similar in both populations. Finally, the PAI delay curve for Population 1 is steeper than for Population 2, reflecting that Population 1 was at greater risk and had less time to respond before potential impact.

Issuance Delay. By dividing the issuance delay time period into a decision-making time and implementation time, we were able to further understand factors that contributed to issuance delay. We documented that factors that delayed issuance time included the lack of hazard maps, planning scenarios, and decision-making aids and plans; lack of pre-scripted warning messages or templates; and the lack of mutually exclusive and redundant warning dissemination technology as well as drills, testing, and exercises.

Diffusion. What we learned in this study was that modern technologies did not perform as rapidly as has been speculated by some researchers and emergency managers. Furthermore, social media played a minor role in the receipt of both the first warning and subsequent warning messages. This again contradicts speculation by some researchers and emergency managers.

Protective Action Initiation. Some people in both study populations initiated evacuation before the first official warning messages were disseminated. Although this type of early evacuation is found in almost all warning events, it is rarely found at the high level observed in this study. Given the potential consequences of the event had it occurred, it is surprising that people in Population 1 did not initiate protective action more quickly after receipt of the first warning. The speed of PAI and the activities taken prior to evacuation was similar in both populations. The percentage of the populations complying with the recommended protective action were lower than expected, particularly in Population 1 where risk was high and available response time was short. The observed compliance rates were nearly identical between the two populations. When controlling for perceived area of risk, compliance rates were higher in Population 1 than in Population 2.

Factors Limiting Generalizations. Generalization of our conclusions are limited by several key factors inherent to the Oroville Dam event. First, the findings are applicable to an area that is comprised of population in rural areas and small urban communities. It is likely that they would not apply in a major urban setting. Second, the conclusions apply to a slow onset event, in this case an event in which considerable risk information was provided to the public for an extended period of time prior to the first official public warning, and may not apply to a rapid onset event occurring over a shorter period of time. Third, conclusions about the impact of modern technology on the diffusion of first warning and PAI timing may not apply in an area that has a greater level of modern technology penetration. Finally, our conclusions are based on data that under-represents people of low socioeconomic status.

Recommended Actions

Future Data Analysis. The Oroville Dam event survey created a wealth of data on warning diffusion, PAI delay time, and the factors that may influence them both. Having this data provides a unique opportunity for analysis. Future data analyses should be conducted to determine which factors best explain and predict variation in these times.

Additionally, the analyses presented in this report regarding issuance, diffusion, and PAI were appropriate for a first level assessment, and hence were largely descriptive. Additional analyses could be performed on these same topics using more specialized approaches or on different data subsets. These analyses could be used to possibly discover additional insights and reach more focused conclusions.

Future Research and Data Collection. Our findings led us to make multiple recommendations about future research and data collection. Identified research needs include:

- Systematic collection of issuance delay data for major flash flood events in general, and for dam incidents and levee failures in particular,
- Survey research data collection on diffusion and PAI for events that represent one or more different characteristics and types of locations including:
    - A rapid onset event (high priority)
    - An event occurring in a highly urbanized area (high priority)
    - Actual flood event (medium priority)
    - Non-evacuation protective action event (medium priority)
    - Nighttime event (low priority)
    - Event involving transportation other than personal vehicles (low priority)

Future Modeling. Although we demonstrated that the existing simulation modeling algorithms are appropriate for short-duration events, there is a need for additional work on modeling events in which warning and PAI take place over time periods greater than four hours.

TABLE OF CONTENTS

LIST OF APPENDICES

Appendix 1.	Inventory of Selected Public Messages
Appendix 2.	Reconnaissance Field Trip Guide
Appendix 3.	Project Description Handout
Appendix 4.	Generic Emergency Manager Interview Schedule
Appendix 5.	Generic Emergency Manager Checklist
Appendix 6.	Generic Emergency Manager Codebook
Appendix 7.	Oroville Public Questionnaire
Appendix 8.	Oroville Public Codebook
Appendix 9.	Oroville Formatted Public Questionnaire
Appendix 10.	Generic Public Questionnaire
Appendix 11.	Generic Public Codebook

LIST OF DATASETS

Dataset 1.	Emergency Manager Interview Data
Dataset 2.	Public Questionnaire Data

1.0 INTRODUCTION

1.1 Purpose

The primary purpose of this study 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 U.S. Army Corps of Engineers (USACE) for use in dam and levee failure loss of life estimation models (Sorensen & Mileti, 2014a, b, c). To accomplish this, it was necessary to collect and analyze data about the performance of a range of warning dissemination channels, including modern technologies, in a recent event in which a protective action warning was issued. New technologies, such as the Integrated Public Alert and Warning System (IPAWS)/Wireless Emergency Alerts (WEA), are promoted by Federal programs. Others are marketed by the private sector. These “modern” technologies include land line telephone with a recorded message, cell phone or other mobile communication device with a recorded message, WEA or SMS (Short Message Service) text messages on a mobile communication device from an official source, and internet-based channels including email, social media such as twitter or Facebook, websites, and more.

Very little scientific research has been conducted on the effectiveness of these modern technologies in emergency events. Effectiveness includes both the speed at which the message reaches the public and the impact of the message on protective action decision-making. In this report, we primarily focus on the effectiveness of the first message diffusion. We also assess the timing of protective action initiation (PAI) based on the channel of first message receipt.

The secondary, but not insignificant purposes of the study were to collect and analyze additional data on the decision-making process leading to the issuance of the warning and the timing of the protective action implementation. In addition, data was collected on the way people implemented the protective action to be used in future analysis.

1.2 Human Warning Factor Elements Investigated

Figure 1-1 illustrates a time sequenced model of warning and response. It consists of three critical time periods: the first alert and/or warning issuance delay time, the first alert and/or warning diffusion time and the PAI time. These time periods have traditionally been the basic inputs for modeling protective action completion such as found in evacuation time estimates (Urbanik, 2000). The warning process begins with the detection of a hazard. That information, sometimes accompanied with an assessment of the risk to potentially impacted populations and protective action recommendation, is communicated to officials with warning responsibilities. The process ends with people implementing a protective action. If such action is completed before the impact of the hazard, loss of life is reduced. Although the process just described and illustrated in Figure 1-1 is represented as linear, it need not be. For example, different process stages may occur in a different sequence (e.g. protective action initiation for some can occur prior to an official warning being issued).

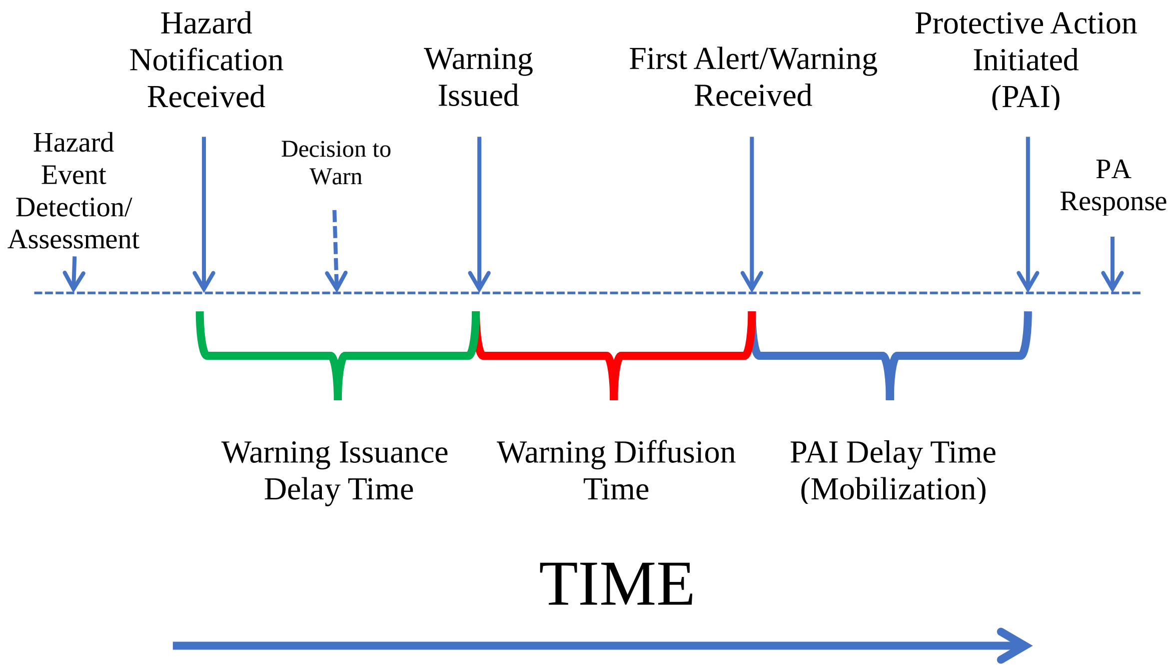


Figure 1-1. Time phased model of warning and response.

1.2.1 Issuance Time

Issuance time has been 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 the warning (Sorensen and Mileti, 2014a). Notification can be formal, for example from a dam operator, or informal such as a person observing a levee breech or overtopping. Based on our preliminary site assessments conducted for the Oroville Dam event we have further refined our conceptualizations of issuance time to include two distinct time periods. The first is time taken to make the warning decision and the second is the time spent to activate the message distribution system. Previously, the literature has not differentiated the two points in time, so observations could have been only for the decision time or the two combined. This differentiation adds more clarity to measurement of this time phase.

1.2.2 Diffusion Time

First alert diffusion time is defined as the time between the point that the local EMA initiates the dissemination of the first alert through the time until the entire at-risk population has received a first alert (Sorensen and Mileti, 2014b). Receipt of a first alert may come from the formal alert/warning system (formal first alert notification) or from secondary non-official sources (informal first alert notification). It is important to understand that the first alert/warning may be received prior to the time of the official decision to warn because of environmental or social cues or when it is received from informal or unofficial sources. Social cues may include seeing or hearing of others taking protective action. Informal sources could include friends and relatives. Unofficial sources may include media reporting that an event may possibly occur, or that a protective action decision such as an evacuation order is imminent.

1.2.3 PAI Time

PAI time is the period between receiving the first alert or warning and initiating the protective action. In this period, people engage in a range of actions before they implement a protective action. Some researchers have labeled this time period as the mobilization time; however, it involves more than merely preparing to take an action. The research record documents several key activities that delay PAI. These are milling or making sense out of the situation, seeking information, reunification with family and intimates, and preparation for each possible protective action.

1.2.4 Protective Action Completion

This final time period, which is not the focus of this report, is the time it takes people to successfully complete a protective action. If the hazard impacts an area before or during the time people are completing a protective action, damages will likely increase. The specific actions that people take determine the time it takes to complete an action. While the major goal of most protective action alternatives is to decrease loss of life and injury, some aim to avoid the loss of property and reduce property damage. Table 1-1 provides a comprehensive set of protective actions for flooding events including those involving dams and levees. In any event, people may engage in multiple protective actions such as taking expedient measures to protect a structure or possessions before evacuating.

Table 1-1. Protective action definitions.

Protective Action	Definition
Evacuate - Vehicle	Driving away from area at risk
Evacuate - Pedestrian	Moving away from the hazard by walking, running or climbing up to higher ground
Evacuate - Vertical	Moving to a higher floor in a structure
Evacuate - Safer Structure	Moving to a nearby structure offering more protection
Avoid Area	Not entering an area of potential threat
Expedient Protection of People	Grabbing hold to a sturdy item or floating item
Expedient Protection of Structures	Improving water resistance or strength of structure (short term – sandbag, seal door frame etc.)
Expedient Protection of Possessions	Moving valuables to a safer location
Seek or Monitor Information	Seeking more information on the event and recommended actions through a variety of actions
Prepare to Evacuate	Packing evacuation kit, review household plan, securing valuables, contact others
Continue Normal Activities	Not changing in daily behavior

1.3 Selection of the Oroville Dam Event for Study

The Oroville Dam event and evacuation that occurred in February 2017 was selected for study for three reasons:

- It was a contemporary event that included the use of modern warning dissemination technologies.
- It involved public warning and protective action recommendations for a large population of people at risk due to a potential failure of the emergency spillway at one of the largest dams/reservoirs in the United States. This type of event does not happen frequently.
- The flood did not happen, which meant that the members of the public who received an evacuation message were not displaced and were readily available for study.

1.4 Collection of Reconnaissance Information

Three different qualitative data collection approaches were used to collect the information needed to learn about the study event and to gather detailed information needed to design subsequent study elements. A summary of these approaches follows.

1.4.1 Internet Exploration

The Internet was explored for as much information related to the study event as we could gather. This was done before we visited the study site. Internet explorations began before the study was funded in April 2017, and continued through August of the same year. The majority of Internet information collection occurred prior to July 2017 when we conducted a site visit to the field to interview key informants.

1.4.2 Community Windshield Survey

The study area was first visited on June 21, 2017 to visually inspect the area, view the Oroville Dam, and examine the evacuated neighborhoods particularly in Butte County, but also in Sutter and Yuba counties. This windshield survey enabled us to determine the degree to which different communities were and were not geospatially distinct from each other and variance in community characteristics, for example, urban versus rural and socioeconomic status. It also provided us with insights regarding the level of complexity that we could and could not include in the questions we would eventually write for the mailed survey questionnaire we would eventually conduct. Finally, it enabled us to view the varied terrain, particularly in Butte County, in terms of low-lying versus elevated geography, which informed the survey sampling approach that was later selected.

1.4.3 Conversations with Key Informants

We conducted a formal reconnaissance trip to the study area on July 18, 2017 through July 23, 2017. Appointments were made with key informants before the trip began. A field guide was prepared to ensure that we did not forget to ask informants key questions (see Appendix 2). We also prepared a one-page project overview to distribute to informants at the outset of our meetings with them (see Appendix 3). We conducted qualitative interviews with the officials responsible for issuing warnings including the sheriffs in Butte, Sutter, and Yuba Counties. To collect information about the decision-making process, we also interviewed key members of the State's Department of Water Resources (DWR) and the Federal Energy Regulatory Commission (FERC) who were instrumental in determining that the risk was critical enough to initiate an evacuation.

1.4.4 How the Reconnaissance Information Contributed to our Study

We collected information regarding the details of the event, how it unfolded, and who the key decision-makers were with regards to the writing and dissemination of the first public warning messages. We met with and introduced the project and ourselves to these key informants. They agreed to be formally interviewed as part of the investigation of warning issuance decision-making (see Chapter 2).

The conversations we had with the key informants also informed us that there were multiple first alert/warning messages issued to multiple geopolitical jurisdictions (see Appendix 1). We collected these warning messages and the time of their public dissemination. Additionally, this information provided us with insights that informed subsequent study design, e.g., which counties to include in the study and the names of different communities in each county to whom evacuation warnings were issued (see Chapter 3).

In short, the reconnaissance field trip enabled us to gather the information needed to conduct research on first warning issuance (see Chapter 2), design the public sample survey and questionnaire (see Chapter 3), study first warning diffusion (see Chapter 4), and analyze public protective action initiation (see Chapter 5).

1.5 Event Overview

Prior to February 2017, the public generally did not consider the consequences of an uncontrolled release of water from the Oroville Dam or the spillway. The dam was simply part of the landscape of the community that had remained virtually unchanged for nearly 50 years.

1.5.1 Event Initiation and Evolution

During the winter of 2016-2017, northern California experienced its wettest winter in nearly a century. Record inflows from the Feather River into the Oroville Reservoir during the month of January caused employees of the California Department of Water Resources (DWR) to open the service spillway and release water at rates up to 20,000 cubic feet per second (cfs). The release of water down the spillway was normal procedure during very wet rainy seasons and that rate of flow is far below the designed capacity of the spillway chute and downstream channel.

In the afternoon of February 6th, in anticipation of increased inflow from an upcoming storm, the flow from the service spillway was increased to 55,000 cfs. The following morning, an unusual flow pattern within the spillway chute caused DWR employees to close the service spillway gates to allow for inspection. The halted water flow revealed a large area of concrete erosion within the spillway chute (see Figure 1-2).

Figure 1-2. A large hole was discovered in the Oroville Dam service spillway chute on February 6, 2017 (Photo courtesy of California DWR).

DWR began consulting with the Federal Energy Regulatory Commission (FERC) and other dam safety agencies the following day. Test flows were occasionally released down the damaged spillway to verify how much flow the spillway could bear. This information was important for the dam operators to know to continue reservoir operations during the rest of the wet season. Further erosion within the spillway chute was carefully monitored and an onsite CAL Fire/DWR Incident Command Post (ICP) was established to oversee the spillway operations.

The Butte County Sheriff's office received an electronic message from DWR to inform them that an investigation was being performed at the flood control outlet of Oroville Dam. It was through social media that the Sheriff learned of the developing hole in the service spillway chute. The Sheriff remained in continuous contact with the ICP to ensure that public safety was the top priority. At this point, it was presumed that the remaining storage area within the reservoir was sufficient to capture the expected flood flows from the rainfall during the rest of that week without causing any threat to the dam or the public. It was the goal of the dam operators to avoid using the emergency spillway while the flood flows were contained, but to be prepared in case using the emergency spillway became necessary. DWR and the Butte County Sheriff's Office kept the public informed through their respective social media platforms.

On February 9th, rainfall of over 12.8 inches over the Feather River Basin caused the inflows into Oroville Reservoir to exceed 190,000 cfs. The peak inflow to the reservoir was significantly higher than originally forecasted. The following morning, flows through the service spillway were raised to 65,000 cfs and the hole within the spillway chute continued to expand and erode portions of the adjacent mountainside. DWR personnel decided to use the emergency spillway to minimize the increasing erosion at the service spillway. Flow through the service spillway was reduced to 55,000 cfs and water level within the reservoir continued to rise.

The emergency spillway had not been used or tested since the dam was constructed. Significant erosion downstream was expected, and DWR employees prepared the face of the mountain by removing brush and trees in the areas where the water was likely to go. The reservoir level reached the emergency spillway crest early in the morning of February 11th.

1.5.2 Pre-warning Communication to the Public of the Potential for Critical Risk

Public information bulletins were distributed to the at-risk public before any official evacuation warnings were issued on February 12, 2017. Two of these came from the Butte County Sheriff. One was issued on February 9th, and the other was issued on February 11th. They are noteworthy because both sought to prime the public for the possibility of an evacuation. These bulletins are shown in Figures 1-3 and 1-4. They indicated that residents in Butte County communities along the Feather River should prepare in the event an evacuation warning is issued.

SHERIFF

KORY L. HONEA
SHERIFF - CORONER

BUTTE COUNTY

FOR IMMEDIATE RELEASE

For Immediate Release: February 9, 2017
Contact: Miranda Bowersox, (530) 990-6949

Butte County Sheriff's Officials, CALFIRE/Butte County Fire, CAL OES, and Oroville City Officials have been participating in briefing meetings held by Department of Water Resources (DWR) pertaining to the Oroville spillway damage. Based on the information received from DWR, there is no imminent or expected threat to public safety or the integrity of Oroville Dam. The emergency spillway may be used as early as Friday evening. This would be the first time the emergency spillway has been used.

Water flowing over the emergency spillway is not desirable because it will result in debris and sediment flowing into the Feather River. These flows will make the river unusually muddy. Water flowing over the emergency spillway does not necessarily mean flooding will occur downstream. Flooding is based on total flow to the Feather River. The current forecasted total flow is not expected to exceed 75,000 cfs, which is less than the flow in 2006 and half of the flow in 1997.

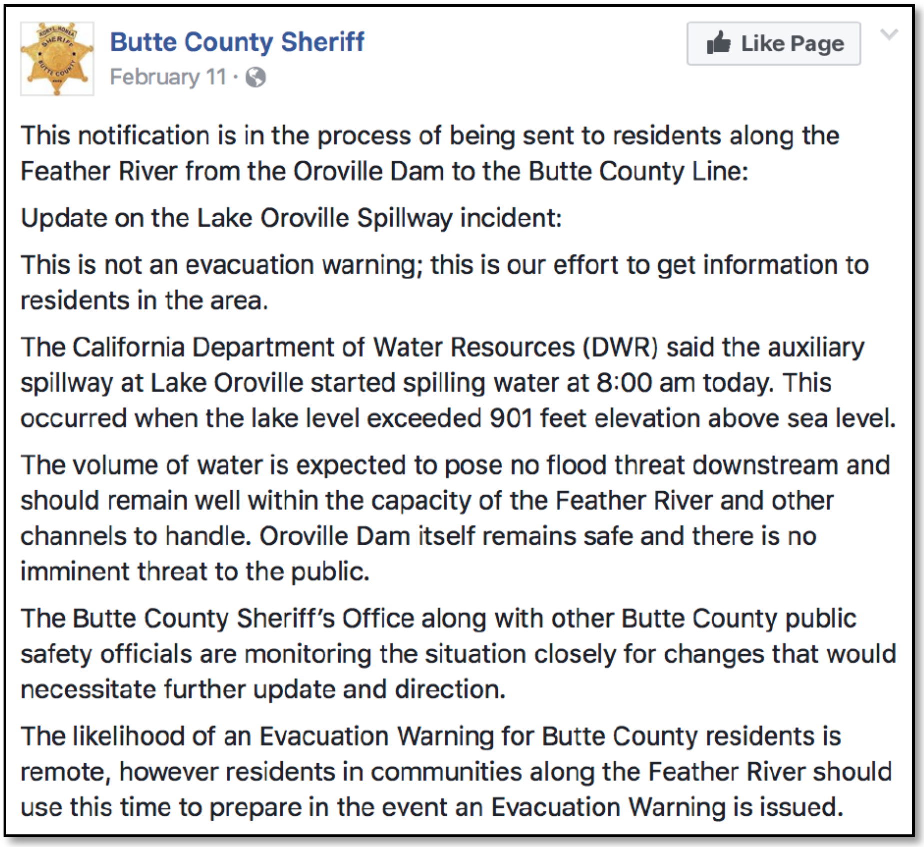
DWR is attempting to avoid the need for flows over the emergency spillway by increasing flows down the primary spillway from 35,000 to 42,000 cfs. The flows through the power plant will increase to 13,000 cfs, for a total of 55,000 cfs being released from Lake Oroville.

Residents in Butte County communities along the Feather River should use this time to prepare in the event an Evacuation Warning is issued. Get ready, gather important items, and consider where you and your family may go if an Evacuation Warning is issued.

Singup for Emergency Notifications at www.buttecounty.net/emergencymassnotification.

A Pubic Information Line has been set up at (530) 538-7826 and will be monitored 24/7.

Figure 1-3. Pre-warning Communication to the Public of the Potential for Critical Risk Issued on February 9, 2017.



Butte County Sheriff
February 11 ·

This notification is in the process of being sent to residents along the Feather River from the Oroville Dam to the Butte County Line:

Update on the Lake Oroville Spillway incident:

This is not an evacuation warning; this is our effort to get information to residents in the area.

The California Department of Water Resources (DWR) said the auxiliary spillway at Lake Oroville started spilling water at 8:00 am today. This occurred when the lake level exceeded 901 feet elevation above sea level.

The volume of water is expected to pose no flood threat downstream and should remain well within the capacity of the Feather River and other channels to handle. Oroville Dam itself remains safe and there is no imminent threat to the public.

The Butte County Sheriff's Office along with other Butte County public safety officials are monitoring the situation closely for changes that would necessitate further update and direction.

The likelihood of an Evacuation Warning for Butte County residents is remote, however residents in communities along the Feather River should use this time to prepare in the event an Evacuation Warning is issued.

Figure 1-4. Pre-warning Communication to the Public of the Potential for Critical Risk Issued on February 11, 2017.

1.5.3 Determination of Critical Risk

In the morning of Sunday, February 12th, work in the ICP was quiet. Water continued to spill over the emergency spillway at a rate that posed no direct threat to the downstream communities. Experts remained at the ICP and at the top of the dam communicating with each other by traveling back and forth or through text messaging with spotty cell reception. Later that morning, geologists noticed erosion cutting back toward the emergency spillway at a rate much faster than anticipated. At approximately 2:00 PM, the erosion began to concern geologists about the safety of the emergency spillway.

If the erosion continued at its current rate and reached the base of the emergency spillway, one of the monoliths could collapse. Engineers were concerned that a failure of one monolith could result in a domino effect and cause the adjacent monoliths of the spillway to successively collapse. Geologists estimated the cutback would reach the base of the emergency spillway in two hours. Decision-makers at the top of the dam discussed when it should be considered an emergency and who had the power to make that decision.

At the Butte County Sheriff's Office, the Sheriff was still in contact with the ICP in the morning of February 12th before the erosion became a concern. Due to the quiet morning and the seemingly expected conditions at the emergency spillway, the Sheriff believed the entire incident was close to its end and decided to take the rest of the day off. On his way home, he went to the ICP to thank the people for their hard work.

Meanwhile, staff monitoring the emergency spillway took photographs of the advancing erosion to the ICP and showed them to the incident commander. The incident commander received the photos at approximately 3:00 PM and was briefed on the developing situation. Some time later, he asked, “Does the Sheriff know about this?”, unaware that the Sheriff was standing behind him. He was told if the emergency spillway were to fail, a wave of water up to 30 feet tall would flow from the breached spillway until the top 30 feet of the lake had drained.

1.5.4 Decision to Evacuate

At 3:30 PM, a meeting was convened including several dam managers, geologists, and the Butte County Sheriff to discuss how to address the situation developing at the emergency spillway. It was decided to allow a flow of 100,000 cfs through the service spillway chute to decrease the water level in the reservoir to below the emergency spillway crest as quickly as possible. It was acknowledged that this would cause additional erosion near the service spillway chute, but would possibly alleviate the risk that the emergency spillway would fail.

During the discussion at the ICP, a dam safety official entered the room and estimated that erosion was moving toward the spillway at a rate of 30 feet per hour. At that moment, the erosion was approximately 30 feet from the base of the emergency spillway. The official recommended that the downstream communities be evacuated in case the spillway were to fail. Everyone present began talking loudly amongst themselves until the Sheriff took control of the room. He asked, “Can anyone here give me a reason not to evacuate?” The room went silent. The decision to evacuate was made at approximately 3:50 PM.

An Emergency Action Plan had been prepared for the dam shortly after the dam was built. An inundation map was included as a part of that plan which showed the areas that would be inundated if the entire dam were to fail. However, a map estimating the flood extents of an emergency spillway failure did not exist. The Sheriff, with the assistance of the dam safety officials, made a conservative estimate on the areas that should be evacuated within Butte County based on the available maps. The Sheriff also called the Sheriffs of Yuba and Sutter Counties. He quickly related that he was evacuating Butte County and they should do the same in their respective counties.

1.5.5 Communication of Evacuation Decision to Other Officials

DWR communicated messages using Blackboard Connect to a range of other organizations about the situation at the Oroville Dam beginning on February 8, 2017. Blackboard Connect is an automated mass notification system that has many capabilities. For Oroville Dam emergencies, it was set up by DWR to send messages to a roster of emergency management and response agencies via email and telephone.

The department distributed the evacuation message using Blackboard Connect to 161 organizational contacts including safety and emergency managers on February 12, 2017 at

4:10 PM. The system re-attempts each contact three times (for those that did not answer the original call) spacing these attempts 10 to 15 minutes apart to have the best chance of connecting with the recipient. The initial evacuation message reached 159 of the 161 contacts on the notification list by 4:44 PM.

This message stated: *"This is an evacuation order. Immediate evacuation from the low levels of Oroville and areas downstream is ordered. A hazardous situation is developing with the Oroville Dam auxiliary spillway. Operation of the auxiliary spillway had led to severe erosion that could lead to a failure of the structure. Failure of the auxiliary spillway structure will result in an uncontrolled release of floodwaters from Lake Oroville. In response to this developing situation, DWR is increasing water releases to 100,000 cubic feet per second. Immediate evacuation from low levels of Oroville and areas downstream is ordered. This is NOT A Drill. This is NOT A Drill. This is NOT A Drill."*

A follow up message which indicated that the spillway would fail within the next 60 minutes and provided guidance on evacuation routes was sent at 4:34 PM and was not completely disseminated until 5:10 PM.

Many individuals on the contact list stated that they found out about the evacuation notice through social media before getting the official message from Blackboard Connect. Possible explanations for this include: (1) Some individuals may have not recognized the number and therefore did not answer the call on Sunday afternoon, (2) Not everyone may monitor their work phone/email on Sunday afternoon, (3) Dozens of messages were sent using Blackboard Connect throughout the five-day emergency, which makes it difficult to remember what messages were received and when.

1.5.6 Chronology of "First" Public Evacuation Messages

Five first public evacuation messages were subsequently issued on February 12th to people in different at-risk geo-political areas. These were: (1) Butte County, which contains the City of Oroville, (2) the National Weather Service to people in Butte, Sutter, and Yuba Counties, (3) Sutter County, (4) Yuba City, which is the largest city in Sutter County, and (5) Yuba County which contains the City of Marysville. First evacuation messages for different subpopulations were catalogued because their timing was central to our efforts to examine warning decision-making, diffusion, and protective action initiation. A broader catalogue of public warning messages can be found in Appendix 1 titled *Inventory of Selected Public Messages*. The five first public evacuation messages follow.

4:21 PM: Butte County. The first public evacuation message was sent to the public of Butte County by the Butte County Sheriff's Office at 4:21 PM on February 12, 2017. It stated the following. *"This is an evacuation order. Immediate evacuation from the low levels of Oroville and areas downstream is ordered. A hazardous situation is developing with the Oroville Dam auxiliary spillway. Operation of the auxiliary spillway has led to severe erosion that could lead to a failure of the structure. Failure of the auxiliary spillway structure will result in an uncontrolled release of floodwaters from Lake Oroville. In response to this developing situation, DWR is increasing water releases to 100,000 cubic feet per second. Immediate evacuation from* *the low levels of Oroville and areas downstream is ordered. This is NOT A Drill. This is NOT A Drill. This is NOT A Drill."*

This message was disseminated using social media, local radio and television, and the Blackboard Connect notification system. The Sheriff also ordered the deputies in Butte County to go to neighborhoods at risk and announce the evacuation order over the PA system in their police vehicles.

4:35 PM: All Three Counties at Risk. The National Weather Service in Sacramento released the following statement at 4:35 PM on February 12, 2017 via Wireless Emergency Alerts (WEA) to everyone in the entire three-county area at risk. *"The National Weather Service in Sacramento has issued a Flash Flood Warning for a dam failure in south central Butte County in Northern California. Until 4:15PM PST Monday. At 4:19PM PST, dam operators reported a hazardous situation is developing with the Oroville Dam auxiliary spillway. Operation of the auxiliary spillway has led to severe erosion that could lead to a failure of the structure. Failure of the auxiliary spillway structure will result in an uncontrolled release of floodwaters from Lake Oroville. In response to this developing situation, DWR is increasing water releases to 100,000 cubic feet per second. Immediate evacuation from the low levels of Oroville areas downstream is ordered. From Oroville to Gridley...low level areas around the Feather River will experience rapid river rises. This is not a Drill. This is not a Drill. Repeat this is not a drill. Locations impacted include Oroville, Palermo, Gridley, Thermalito, South Oroville, Oroville Dam, Oroville East and Wyandotte. Turn around, don't drown when encountering flooded roads. Most flood deaths occur in vehicles. Move to higher ground now. Act quickly to protect your life."*

5:33 PM: Yuba County. The Yuba County Office of Emergency Services issued the following warning message to people in Yuba County at 5:33 PM on February 12, 2017. *"ALERT-ALERT-ALERT –- Yes, an evacuation has been ordered. All of Yuba County on the valley floor. The auxiliary spillway is close to failing. Please travel safely. Contact family and friends. Help the elderly. Take only routes to the east, south, or west. DO NOT TRAVEL NORTH TOWARD OROVILLE!!!!!"* At 5:48 PM, the Marysville Police Department confirmed that a mandatory evacuation for the City of Marysville and Yuba County was in effect. Then at 6:08 PM it was stated that: *"Evacuation for Yuba includes Hallwood, Marysville, Olivehurst/Linda and Plumas Lake due to potential failure of Oroville Dam spillway."*

6:03 PM: Sutter County. At 6:03 PM on February 12, 2017, the Sutter County Office of Emergency Management issued the following message to people in Sutter County. *"Immediate evacuation Live Oak, Yuba City, Nicholas and other communities along Feather River ordered. Evacuate on Highway 99/70 south of Highway 20 west. Do not evacuate north. A partial failure of the Oroville Dam is possible."* The county followed this first evacuation message to people in Sutter County with a subsequent message at 6:17 PM, which declared that the evacuation was ordered (or mandatory). *"Immediate evacuation ordered for Live Oak, Yuba City, Nicholas & all communities Feather River Yuba City basin. Evacuate West on Hwy 20 and/or South on Hwy 99 and Hwy 70 toward Sacramento."*

6:49 PM: Yuba City. Another public evacuation message was issued which targeted the people in Yuba City which is located in Sutter County. It was distributed at 6:49 PM on February 12,

2017. It was the first message issued by city officials and it followed the mandatory evacuation message distributed by the County. It contained a voluntary evacuation recommendation, and was issued by local Yuba City government. It stated the following. *"City of Yuba City strongly recommends an evacuation of all residents immediately. Travel options are as follows. South on Highway 99, West on Highway 20, Highway 99 South to Highway 113, or South on George Washington to Highway 113. Do not travel on Highway 20 or Bridge Street as the bridges are closed. Do not travel North."*

1.6 Conclusions

The incident at Oroville Dam provides a unique opportunity to study the warning issuance, warning diffusion, and protective action initiation. It is unique because the potential for catastrophic flooding was high. Had the emergency spillway failed on Sunday evening, significant flooding would have occurred. Such events do not occur very often. It was also unique in that the event did not result in significant damage and displace people living downstream from the reservoir. People were therefore available to be contacted about their warning experiences.

2.0 WARNING ISSUANCE DELAY

2.1 Purpose

The purpose of this chapter is to further define what we mean by warning issuance, refer readers to where they can find detailed information regarding the factors that influence warning issuance delay, discuss how data was collected on issuance delay for the Oroville event, and present the findings from a descriptive analysis of the data. In this chapter, we differentiate between the jurisdiction adjacent to Oroville Dam (Butte County) versus the two jurisdictions (Sutter and Yuba Counties) further downstream of the dam.

2.2 Warning Issuance Delay Defined

Warning issuance delay has been previously defined as the time it takes for official alert and warning providers to reach a decision to issue a first alert or warning to the public after they first become initially aware of a hazard's pending impact (Sorensen and Mileti, 2014a). Initial impact awareness can occur in a variety of ways: for example, receiving notification about it from those who monitor the environment or a technology, by detecting a hazard's pending impact themselves, or even by a member of the public who observed it by chance. Hence, initial notification can be formal, for example from a dam operator, or informal such as a person observing a levee breach or overtopping. This view limits issuance time to the amount of elapsed time between when initial notification or awareness begins and when the alert or warning provider decides to issue a first alert or warning. Obviously, warning issuance delay can be somewhat unique for each hazard event, and it can influence event consequences particularly in rapid onset events. Unfortunately, it has rarely been systematically measured or even recorded.

We have expanded this view of warning issuance delay by adding another time period to account for the time between when a decision is made to issue a first public alert or warning and the time when the warning system was first activated to disseminate the message to the public. This time period may involve implementing a pre-planned warning activation procedure or it can be ad-hoc in cases where no such procedures exist. This time period can range from a very short time to a lengthy one, and its length can be influenced by situation-specific factors such as the location where the decision is made, the availability of personnel, the types of warning dissemination channels used, the procedures implemented and more. Hence, the expanded model of issuance delay used in this study includes three rather than two points in time as follows:

- Time 1: The time when official public alert and warning providers are first notified of a pending hazard's impact that could threaten public safety.
- Time 2: The time when those officials decide to issue a public alert or warning.
- Time 3: The time when the first public alert or warning is first disseminated to the public.

It is also important to point out that another time period prior to notification may be relevant. This can be referred to as a "heightened awareness" phase. This phase begins with an event or conditions that may be precursors to a flood, but not to the extent that public action, other than monitoring the situation, are needed. For the Oroville Dam event, this began on February 7th, five days prior to the evacuation. On February 12th, the day of the evacuation, the level of concern elevated when the erosion below the emergency spillway was observed and monitored. This suggests that during this heightened awareness phase, the perception of the risk of a flood event may shift.

In situations that involve multiple jurisdictions where the risk to the public in those jurisdictions differs because of variations in lead-time to impact and/or magnitude of impact, the time of first public notification may be different for longer lead time/lower risk jurisdictions. Such was the case in the Oroville Dam event.

2.3 Instrument Development, Pretesting, and Data Collection

2.3.1 Instruments

Three instruments were developed to measure warning issuance delay. These were constructed to measure this variable and many others including some which the research literature has documented to influence warning issuance (see Section 2.4). The instruments developed were:

- Generic Emergency Manager Interview Schedule (see Appendix 4),
- Generic Emergency Manager Checklist (see Appendix 5), and
- Generic Emergency Manager Codebook (see Appendix 6).

The interview schedule was used to conduct interviews with the sheriffs in each of the three study communities. The checklist and codebook were prepared for possible future USACE research.

2.3.2 Instrument Development and Pretesting

The initial draft of the instrument was developed from the emergency managers checklist developed in a previous project (Sorensen and Mileti, 2014a). This checklist was designed to measure factors that may influence first alert timing based on community planning and response infrastructure. This checklist was revised to apply generically to an actual warning event. The reconnaissance interviews played a major role in the decision to shorten the interview schedule by focusing on the issuance process and timing rather than the factors that influenced timing. The checklist was then pre-tested with the following emergency management organizations:

- Yolo County, CA
- Sacramento County, CA
- Scott County, IA
- Kay County, OK

Two of the organizations were familiar with the Oroville Dam event but were not directly impacted. The remaining two have dealt with flood incidents in general. These organizations were selected to ensure that the instrument would be applicable to the Oroville Dam event as well as studies of future flood events throughout the country. All comments were collated on a single interview schedule and were used to prepare the final instrument.

2.3.3 Data Collection

When the instrument was finalized, it was initially filled in using the field notes from the reconnaissance trip where interviews were conducted with the sheriffs in each county. Once these were complete, telephone calls were scheduled with the sheriffs to fill in any missing data and to confirm any information that was unclear from the reconnaissance interviews. In addition, one other organization was interviewed on the phone that was not originally contacted, the Yuba County Emergency Services Office, which participated in the County's evacuation warning decision.

2.4 Factors That Influence Warning Issuance Delay

We have developed a good understanding of what causes some communities to make rapid warning decisions with minimum delay and those that take longer to begin warning dissemination. A complete discussion of these factors can be found in earlier work prepared for the USACE (Sorensen and Mileti, 2014a). These factors fall into four general categories that are briefly described below.

First is the formalization of planning and implementation procedures. Communities that have thought through the warning decision process and prepared plans, procedures and the relevant tools for arriving at rapid decisions will perform better than those communities who have left warning decisions to be made in an ad-hoc manner. Although many communities have adopted an incident command decision structure, it is unclear what impact this type of structure has on the timing of warning issuance.

Second are the performance and interpersonal relations factors. Having been trained on the warning issuance process and exercised it on a periodic basis will improve the effectiveness of the decision process. Moreover, understanding the communications process and knowing the people one is communicating with will also reduce issuance time. Flexibility in adapting to new and unforeseen situations will also reduce delays.

Third are system performance factors. Having hardened and redundant communications can prevent technology failures from interfering with making decisions.

Fourth are situational factors. Some of these can be effectively controlled while others require adaptive planning procedures to overcome detrimental effects. Warnings are delayed when incidents occur during the night versus during the day. If the event that caused the emergency impacts electricity supply or the physical infrastructure of the community, delays may be unavoidable. Environmental cues such as the lack of rain during a flood event may cause decision-makers to delay decisions. The urgency of the need to make a decision can be a strong motivation to reduce delays in warning.

2.5 Issuance Factor Measurement

The factors described in the section above were not extensively measured in the current project. Our purpose was not to predict warning issuance time in the Oroville Dam event, but rather to gather descriptive details about how warning issuance unfolded, e.g., what led up to issuing the first public evacuation warnings. Furthermore, the emergency manager interview schedule needed to be shortened based on the results of the pretest. The variables we sought to measure are presented in the Emergency Manager Codebook in Appendix 6.

We sought to measure issuance related factors that fit into the following categories:

- The plans jurisdictions had in place before the Oroville event began,
- How the decision was made to issue first public warning messages during the event and how those warnings were distributed, and
- Public warnings and message issued to the public after the first warning messages were distributed.

The first questions we asked were about pre-event plans and information before the Oroville Dam event began. We asked if a general operations plan was in place before the event (Q1), if there was a warning annex to the general plan (Q2), if there were standard operating procedures in place for alerts and warnings (Q3). We also asked if flood inundation maps were available to emergency managers before the event began, and if any were made available during the event (Q7).

The next set of questions made up the bulk of the interview schedule. We asked the date and time emergency managers first learned that a flood event may occur (Q8), who communicated that information to them (Q9), and how it was communicated (Q10). We also asked if the emergency manager communicated with people responsible for monitoring the dam before making the decision to issue the first public evacuation decision in their jurisdictions (Q11), how the decision was made to warn the public (Q12), who made the decision to warn the public (Q13), and the date and time the decision to warn was made (Q15).

Other details were explored by asking how much time elapsed between making the decision to warn the public and when the public was warned (Q16), who prepared the first message (Q18), if the message was coordinated with other jurisdictions (Q19), and how long it took to prepare the message (Q20).

We then began a series of questions about how the first warning message was communicated to the public. We asked if a multiple channel distribution system was used (Q22), and about specific different channels and technologies available to disseminate public warnings (Q23). Q24 asked if any warning delivery technology failed during the event. And we inquired if any special dissemination technologies were used to reach special subpopulations including people who might be boating or camping, agricultural workers, the homeless and more (Q25).

We continued by asking about special ways to reach the people closest to the dam (Q26), special ways they might have tried to reach the hearing impaired (Q28) or visually impaired (Q29), and if warning messages were delivered in more than one language (Q30).

The last questions we asked were about additional messages that may have been issued after the first warning message was disseminated. For example, we asked if the first warning was distributed more than once (Q32), if subsequent messages were used to provide the public with revised or updated information (Q33), and we also asked about all of the communication channels and technologies that may have been used to reach the public over the lifetime of the event (Q34).

2.6 Data Analysis and Presentation

In this section, we present our findings on issuance delay in the Oroville Dam event. First, we examine the timeline of key events on a county basis. Second, we examine issuance delay times calculated from the timeline. Third, we present a summary of community characteristics for these three jurisdictions that may influence issuance delay. Finally, we identify the channels that county officials used to disseminate the first alert.

2.6.1 Issuance Timeline

The timeline for the spillway incident began sometime on Sunday afternoon (see Table 2-2). Engineers and scientists at Oroville Dam were monitoring dam conditions including the erosion that was taking place below the emergency spillway. This information was being communicated to the onsite CAL Fire/DWR Incident Command Post (ICP) located to the south of the service spillway. The Butte County sheriff was at the onsite ICP the morning of the 12th and was preparing to leave when information coming from scientists monitoring the erosion caused concern for California DWR officials at the ICP. Specifically, concern was expressed that if erosion below the spillway continued at the observed rate, the spillway could fail. To the best of our judgement, the Butte County Sheriff learned of this around 3:30 PM prompting a meeting that would lead to the decision to evacuate.

Table 2-2. Notification, decision, and first warning message distribution times on February 12, 2017 by jurisdiction.

Jurisdiction	Notification Time*	Decision Time*	Message Distribution Time*
Butte County	3:30 PM	3:50 PM	4:21 PM
Sutter County	5:00 PM	5:50 PM	6:03 PM
Yuba City	4:30 PM	unknown	6:49 PM
Yuba County	4:00 PM	4:45 PM	5:33 PM

**These are best estimates based on a variety of sources*

At some point in this meeting to discuss the implications of the observed erosion rate, it was mentioned a spillway failure would result in a 30-foot wall of water being released from the reservoir. At that time, the only inundation map at the ICP was for a total dam failure. When the Sheriff asked what the map said about downtown Oroville, he was told it would be under 150 feet of water. The sheriff then asked how long it would take for the situation to get under control and was told it would take several hours. He asked how long it would be before a spillway failure and was told the erosion rate was 30 feet per hour and that the erosion was about 30 feet away from the emergency spillway monoliths. He then asked them “so we basically have an hour?” The response was “yes, it appears that way.” At that point, the sheriff asked very loudly for everyone to be quiet and to listen to him. He then stated that we need to evacuate the people of Oroville and asked if anyone disagreed with that. There was silence. Then he was told “you got to do it, Sheriff.” It was 3:50 PM. The Butte County Sheriff then began to work with California DWR to craft a warning message, make calls to activate the county warning system, and notify sheriffs in surrounding counties. The best estimate for the initial warning message dissemination was at 4:21 PM.

The decision-making and warning issuance in other jurisdictions followed from the initial set of events in Butte County. Yuba County to the Southeast of Butte was on a high alert status due to the high water levels at Oroville Dam and other reservoirs in the county that posed flood threats when the Sheriff received a 4:00 PM phone call from the Butte County Sheriff stating that he was evacuating the county. The Sheriff of Sutter County to the southwest, recalled being notified around 5:00 PM by California DWR. The Yuba City after action report stated that the Fire Department was notified at 4:30 PM.

In Yuba County, the Sheriff went to the County Emergency Operations Center following the initial contact to meet with the county emergency services director and fire personnel. After informing county officials, a decision to issue an evacuation warning was made around 4:45 PM. The first alert message went out sometime later, in part due to a failure of the multiple channel dissemination system.

In Sutter County, the decision was made by the Sheriff, fire chief and county administrator to evacuate following Butte County’s decision. That decision was made around 5:50 PM and the first public warning message went out at 6:03 PM.

2.6.2 Issuance Delay

Figure 2-1 graphically depicts the issuance delay for the three counties issuing protective action warnings on February 12, 2017 in response to the possible spillway failure at Oroville Dam. It shows both the time from notification to decision and from decision to dissemination. Yuba City sent out their first notification at 6:49 PM, however no decision time is available. Furthermore, this notification came after the one issued for the entire county, so it was not truly a “first alert” for that population. Issuance delays are summarized in numeric form in Table 2-3. Jurisdictions are classified as to whether they are in close proximity to the source of the threat (adjacent) or further away (downstream).

These issuance times are not a measure of the effectiveness of a warning system or the organizations issuing warnings. They represent the dynamics of dealing with a situation marked by uncertainty, less than perfect data, and the science to interpret available data. Butte County, the adjacent jurisdiction, took a shorter time to make the decision because their decision was intertwined with the monitoring and risk assessment process. If they had not been part of that process, the decision might have taken a longer total time. They were also at highest risk and had a very short lead time to impact.

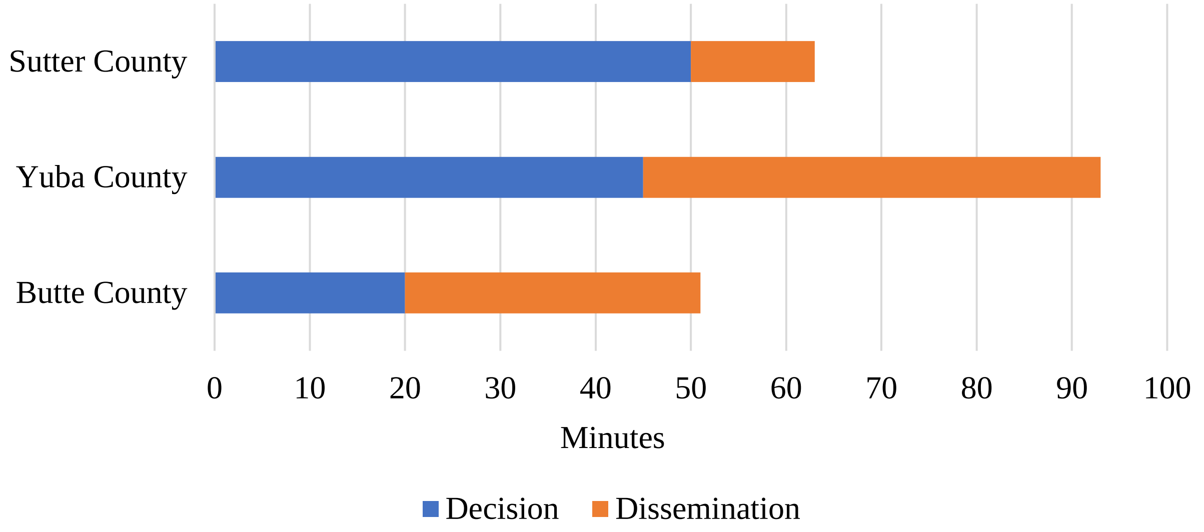


Figure 2-1. Histogram of issuance decision and dissemination delay by jurisdiction.

Table 2-3. Issuance decision and dissemination delay times by jurisdiction.

County	Jurisdiction Location	Decision Delay *(minutes)*	Dissemination Delay *(minutes)*	Total Issuance Delay *(minutes)*
Butte County	Adjacent	20	31	51
Yuba County	Downstream	45	48	93
Sutter County	Downstream	50	13	63

Decision times for Yuba and Sutter County were longer because, as downstream jurisdictions, they were not dealing with imminent threat. The times between the decision and dissemination varied by county. Butte County's dissemination was likely delayed by the time it took to write the warning message. Yuba County's dissemination was delayed by technical issues with system activation controls. Sutter County dissemination delay was shorter because there were no technical problems sending out the first alert. Both Yuba and Sutter County needed to prepare the message but could follow the evacuation message prepared by Butte County and the DWR and was bolstered by their experience with evacuating the areas due to historic flooding problems not associated with dam failure.

2.6.3 Community Factors

Factors that may impact the amount of time a jurisdiction takes to make a warning decision and disseminate the warning were assessed. These factors are summarized in Table 2-4. The letter "Y" indicates the factor is present. Some of the factors were directly measured in interviews while others were coded based on the review of secondary information sources.

Table 2-4. Factors impacting issuance delay timing by jurisdiction.

Factors Measured by the Interview Schedule	County		
	Butte	Sutter	Yuba
General Emergency Operations Plan (EOP)	Y	Y	Y
General Warning Plan/Annex	Y		
Standard Operating Procedures (SOPS) For Alerts/Warnings	Y		Y
Field Operations Guide (FOG) For Alerts/Warnings		Y	Y
Hazard-Specific Warning Plan			
Hazard-Specific Standard Operating Procedures (SOPS)			
General Flood Hazard Inundation Maps	Y	Y	Y
Event Specific Flood Hazard Inundation Maps			
Political Clearance/Approval Needed			

Factors Measured by Secondary Means	County		
	Butte	Sutter	Yuba
Warning Thresholds (Matrix)			
Clearly Defined Authority	Y		Y
Identified Responsibilities	Y		Y
Interagency Communication Procedures			
Failsafe Communications			
Pre-scripted Messages			
Single Decision Maker	Y		
Short Time to Impact	Y		

Given the small number of cases (3) in our study, it is impossible to estimate the impact these factors had on the issuance delay times observed. Based on earlier work, the main factor that may have lengthened decision time was the lack of warning thresholds that link failure scenarios to protective action warnings. This was evident in all jurisdictions, but was particularly problematic in the adjacent high-risk jurisdiction (Butte County). The main factor that may have lengthened warning issuance time was the lack of pre-scripted warning messages. In the adjacent county, it likely added 15 to 20 minutes to warning issuance delay. This was less critical in downstream jurisdictions (Sutter and Yuba Counties) because they would have had more time before impact. Uncertainty concerning conditions at the dam likely also delayed decision-making. Uncertainty can be overcome by threat-based planning matrices that trigger emergency warnings. In addition, the failure of warning system activation technologies to perform is a key factor to account for in examining dissemination delays. Overall the findings provide strong support for a comprehensive risk-based approach to planning.

2.6.4 Warning Distribution Channels Used for First Alert

Several channels exist for disseminating warnings to the public. Table 2-5 summarizes the channels used to distribute the initial warnings to the public in the three at-risk counties. These channels are the ones specified by emergency managers that were interviewed.

As expected, not all channels were used by any single jurisdiction. The channels used represent a mix of both older traditional channels such as route alerting by police or fire personnel going door-to-door or down streets with loudspeaker and newer technologies such as text messaging or emails. How these channels performed in disseminating the message is examined in the next chapter.

Table 2-5. Channels used to distribute first warning message by jurisdiction.

Channel	County		
	Butte	Sutter	Yuba
Multiple Channel Distribution System	Y	Y	Y
Route Alerting	Y	Y	Y
Fixed Location Loudspeakers/PA			
Wireless Emergency Alerts (WEA) County			
Wireless Emergency Alerts (WEA) NWS	Y	Y	Y
Short Message Service (SMS)	Y	Y	Y
Radio	Y	Y	Y
Television	Y		
Press Conference			Y
Newspapers	Y		
NOAA Weather Radio			
Dedicated TA Radio			
Audio Sirens			
Electronic Sirens (Voice)			Y
Message Signs			
Aircraft			
Visual Alerting			
E-mail	Y		Y
Text Messages		Y	Y
Social Media	Y	Y	Y
Website		Y	Y
Reverse Telephone System	Y	Y	Y
TTD/TTY			Y

2.7 Conclusions

In the Oroville Dam event, the warning issuance delay for Butte County began when the onsite CAL Fire/DWR ICP, responsible for monitoring data collection at the dam and assessing risk, learned that a spillway failure could occur based on field observations of erosion below the spillway. They communicated that information to the Butte County Sheriff who was at the ICP. The time between that point and the dissemination of the first public warning is the issuance delay for Butte County. Since the process of warning issuance was examined in detail, we can determine the point in that process when the decision to implement the warning was made and when the first message was disseminated for all three jurisdictions. This represents a more refined definition and measurement of issuance delay than was previously possible given limited systematic observations.

Issuance time was also likely decreased for Butte County since they were present at the onsite ICP when the critical information came in from the dam. If the Butte County Sheriff had been absent from the ICP and was contacted later by the ICP about the situation, the issuance delay would have been longer.

In all jurisdictions, issuance time delays may have been reduced by more risk-based planning. The establishment of thresholds that trigger protective action warning could have helped in addressing the uncertainty in decision-making. In addition, regular testing of warning dissemination technologies might have prevented delays in distributing the message in certain risk areas. While these delays were not life-threatening in this event, they could be in rapidly unfolding events.

The establishment of a systematic approach to collecting issuance time data and the relevant community characteristics were outlined in this chapter. If such data collection efforts are institutionalized for all flash flood events in general, and for dam incidents and levee failures in particular, then our understanding of issuance delay will be greatly improved. This will allow more robust assumptions to be made and algorithms refined in models simulating the loss of life for flood events. The systematic study of issuance delay as suggested would not be a time consuming or expensive endeavor.

3.0 SURVEY METHODS FOR THE STUDY OF WARNING DIFFUSION AND PROTECTIVE ACTION INITIATION (PAI)

3.1 Purpose

We surveyed public households in two separate and distinct populations to assess the diffusion of first public alerts/warnings and protective action initiation (PAI). A mailed questionnaire was sent to a statistically representative sample of households in the subset of places at risk in Butte County (Population 1); and to another statistically representative sample of public households in places at risk in a combined population of Sutter and Yuba Counties (Population 2).

The purpose of this chapter is to describe the research methods used in these surveys. Topics covered include the populations studied, the statistically representative samples selected to represent those populations, identified biases in the samples, questionnaire construction, the questionnaire clearance and approval process with the Office on Management and Budget and the Internal Review Board at California State University Fullerton, how we mailed and tracked returned questionnaires, the incentive provided to respondents to enhance respondent participation, and other topics related to the collection of questionnaire data from the people who experienced the February 2017 Oroville Dam event.

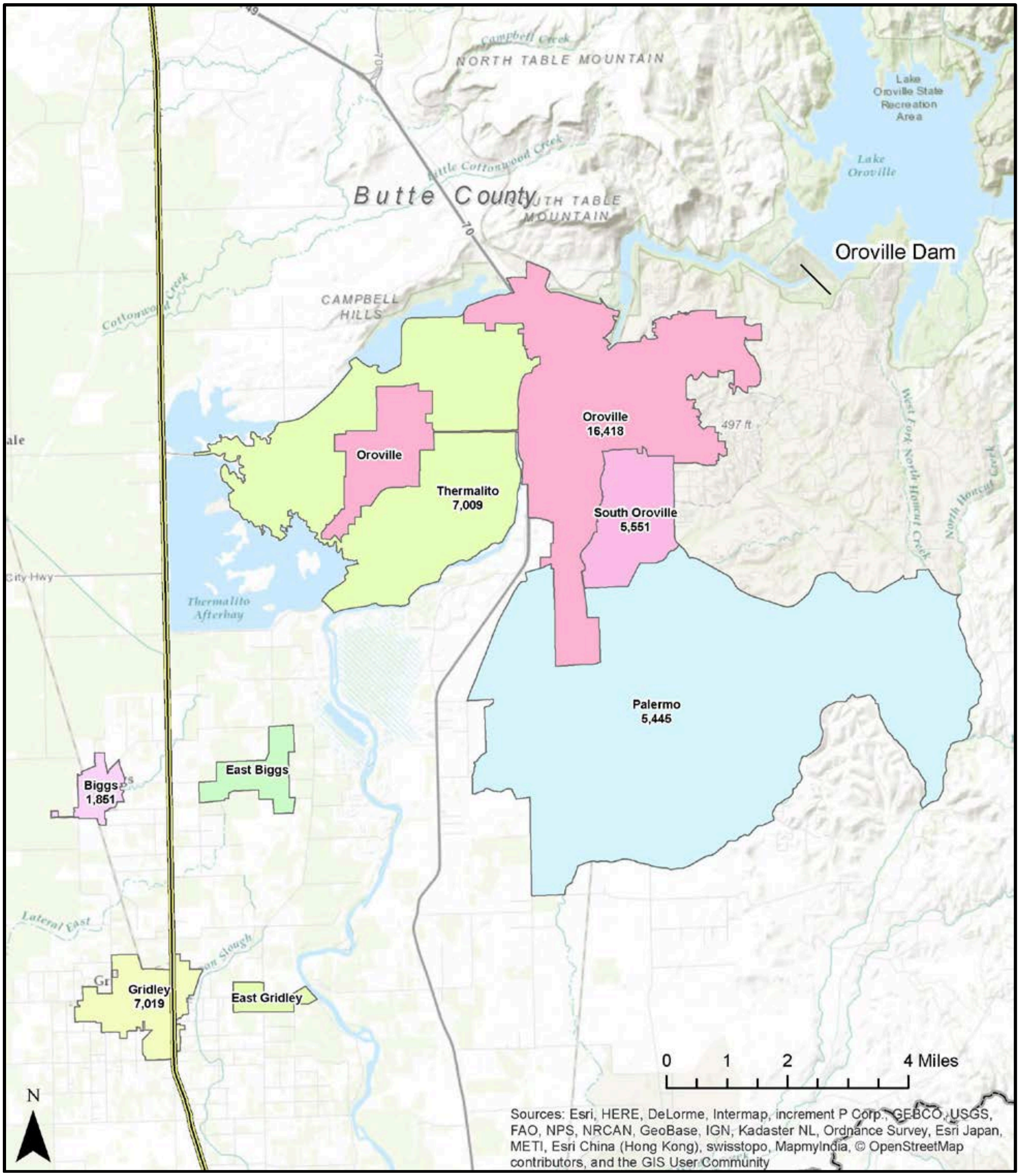
3.2 Definition of Two Study Populations

People in three different counties were issued first alert/warning messages to evacuate. We developed a research design to collect and analyze data on diffusion and PAI in all three of these counties. The counties were divided into two separate household study populations as follows.

Population 1 was defined as the subset of households in Butte County who were targeted in the first evacuation alert/warning issued. This population was closest to the Oroville Dam, had the highest and most immediate risk, and households in this population were provided the least time to evacuate had a flood occurred. It was determined during our pre-survey field investigation (see Chapter 1) that this population included the communities listed below (2016/2017 population sizes are listed in parentheses). Community population sizes were obtained from either Hometown Locator, (http://www.hometownlocator.com) or from Suburban Stats (https://suburbanstats.org), which are national commercial demographic services. Household counts (provided after population estimates) are from the 2010 US Census.

- City of Oroville (16,418 individuals/5,646 households)
- South Oroville - Census Designated Place (5,551/1,745)
- Thermalito - Census Designated Place (7,009/2,263)
- City of Biggs (1,851/565)
- East Biggs - Census Populated Place (population unknown/household count unavailable)
- City of Gridley (7,019/2,183)
- East Gridley - Census Populated Place (population unknown/household count unavailable)
- Palermo - Census Designated Place (5,445/1,940)

Figure 3-1 shows the geographical location of these Population 1 cities, towns and places in Butte County. Excluding those areas for which no population data was available (presumed to be areas with negligible populations), the total size of this population was approximately 43,293 people. The estimated number of households as of 2010 was 14,342.



Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 3-1. Butte County communities included in survey Population 1.

Population 2 was defined as the subset of households in a combined population of households in both Sutter and Yuba Counties. Households in these counties were also issued first evacuation messages from their own county alert/warning originators. These counties were a greater distance from the Oroville Dam and would have had more time to evacuate had a flood occurred. Hence, to achieve an economy of research scale, households in these counties were combined into the same second study population.

These households had lower risk since they were most distant from the dam, and they would have had the most time to evacuate prior to impact had a flood occurred. It was determined during our pre-survey field investigation (see Chapter 1) that this population included the communities listed below (2016/2017 population sizes are once again listed in parentheses next to the name of each community). Community population sizes were obtained from either Hometown Locator, (http://www.hometownlocator.com) or from Suburban Stats (https://suburbanstats.org), which are national commercial demographic services. Household counts (provided after population estimates) are from the 2010 US Census.

The communities in Population 2 from Sutter County included the following:

- Yuba City (66,628/21,550)
- Lomo - Census Populated Place (69/household count unavailable)
- City of Live Oak (8,870/2,331)
- Tierra Buena (population/household count included in Yuba City)
- East Nicolaus - Census Designated Place (232/88)
- Nicolaus - Census Designated Place (217/92)
- Rio Oso - Census Designated Place (362/124)
- Pleasant Grove - Census Populated Place (892/household count unavailable)
- Robbins - Census Populated Place (323/107)

The communities in Population 2 from Yuba County included the following:

- City of Marysville (12,519/4,668)
- Hallwood - Census Populated Place (population unknown/household count unavailable)
- Linda Census Designated Place (19,207/5,440)
- Olivehurst Census Designated Place (14,087/4,120)
- Plumas Lake Census Designated Place (6,646/1,745)
- City of Wheatland (3,753/1,219)
- District 10 (population unknown/household count unavailable) is located north of Marysville to the Butte County boundary and includes the small places of Mello, Ramirez, and Tambo each of which have an unknown population and for which household counts are unavailable

Figure 3-2 shows the geographical location of these Population 2 cities, towns and places. Excluding those areas for which no population data was available (presumed to be areas with negligible populations), the total size of this population was approximately 133,805 people. The number of households, as of 2010, was 41,484.

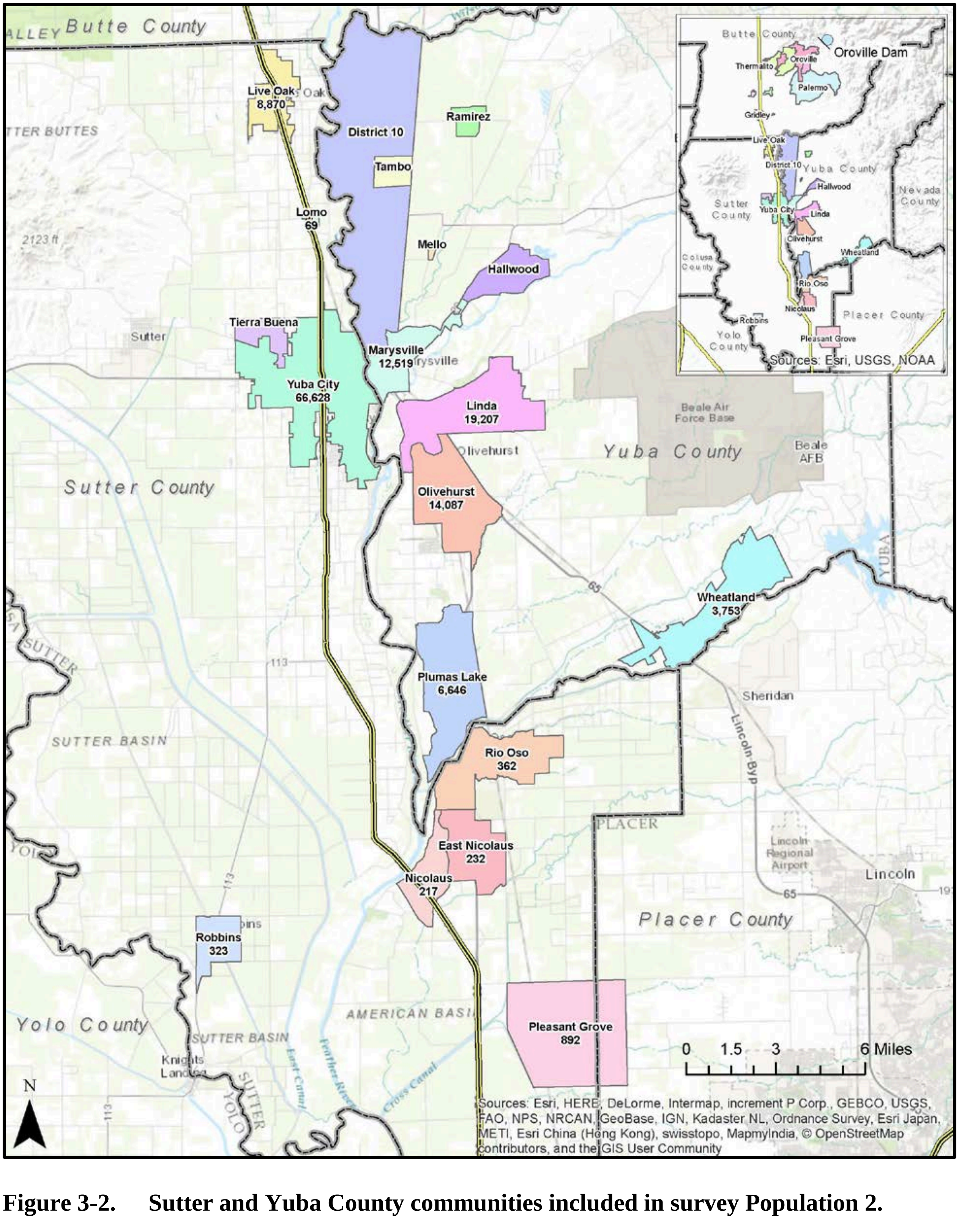


Figure 3-2. Sutter and Yuba County communities included in survey Population 2.

3.3 Sample Survey Firm

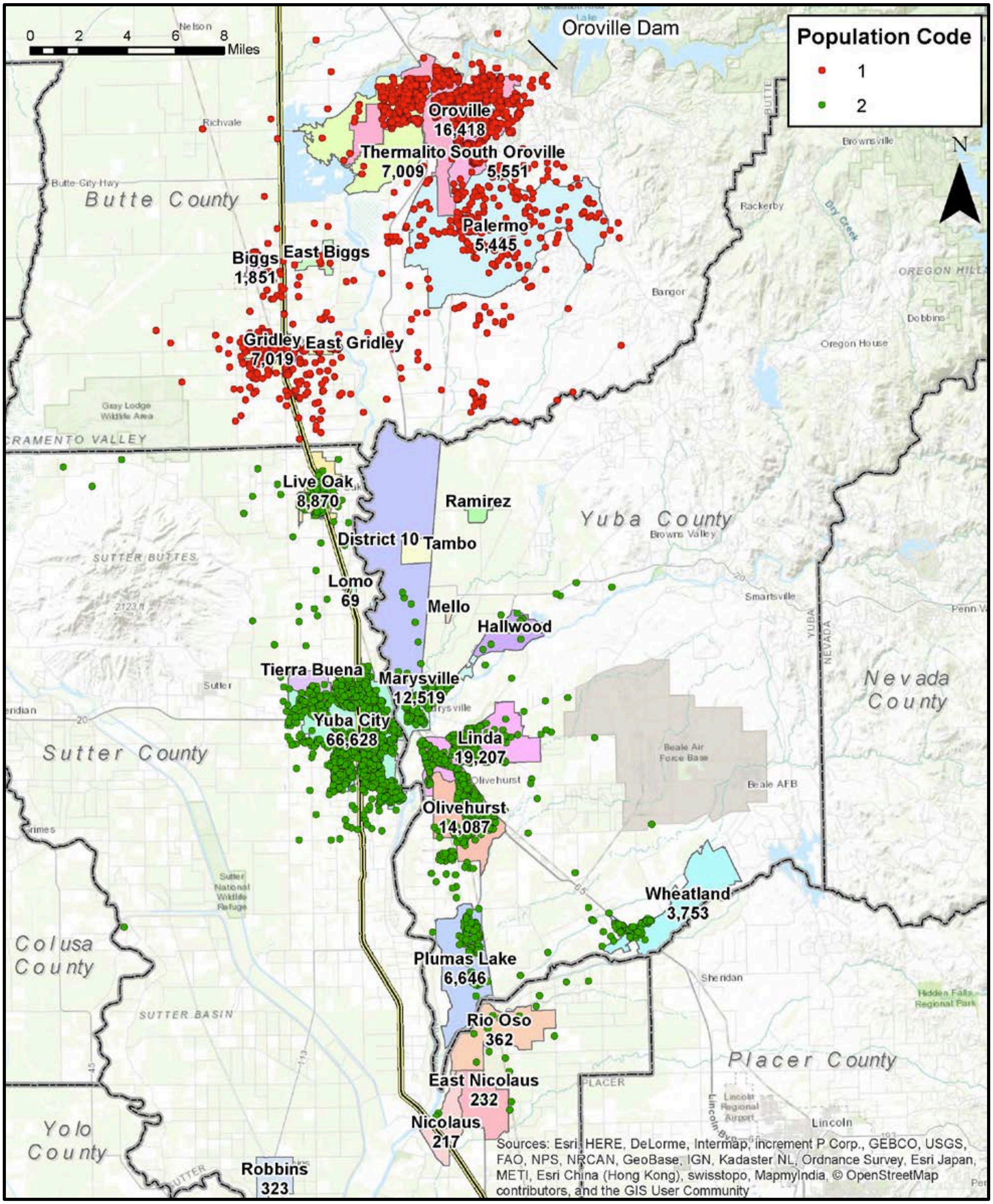
A sample survey firm was hired to assist us with the detailed logistics of conducting two mailed household surveys, coding and quality control of the data from the returned questionnaires, and creating a database for analysis. The firm selected was the Social Science Research Center (SSRC) at California State University Fullerton. A detailed list of work assignments was prepared and sent to the SSRC. A face-to-face meeting followed this to review and discuss the research plan and the exact work the firm would conduct. A contract between the SSRC was then put in place. Drs. Sorensen and Mileti oversaw this work as it moved forward and ended in a face-to-face meeting in the offices of the SSRC to review and begin analysis of the data.

3.4 Sampling Strategy

To obtain representative samples of randomly selected households in both study populations, the survey firm (SSRC) worked with Scientific Telephone Samples (STS), a premier vendor of statistically sound address-based samples, to enumerate a list of all households falling within the target populations defined above. The typical sampling strategy to define an address-based sample is through Census block groups. This was problematic for the geographically small and oddly shaped study areas since they were defined by areas subject to floodwaters rather than by standard geopolitical boundaries. Additionally, the study populations included several sparsely populated towns or Census Designated Places (CDPs) with poorly defined geographical boundaries. For example, some of these places overlapped with multiple block groups, while for others, a large proportion of the block group fell only partially within a study area.

To address this issue, a list was created of all block groups that fell either fully or partially into the geography study area for each population. Block groups that were clearly outside the study areas were eliminated. All households from the remaining block groups were included in the pool from which residences were drawn for potential inclusion in the samples, regardless of the proportion of the group that fell within the study area. However, of the 145 block groups included, the majority (*n* = 123; 84.8%) had 100% of their households within a study area.

A total of 2,500 addresses were then randomly selected from this pool for each study population (Population 1: 2,500 + Population 2: 2,500 = 5,000 selected overall), such that each of the locations within the study populations would be represented proportionally. Figure 3-3 shows the geographic distribution of the addresses selected for each population. These addresses comprised the sampling frame and were estimated to be an adequate number to obtain a sufficient number of returned questionnaires from both populations—this topic is addressed in more detail in a subsequent section of this chapter. The survey incidence or completion rate (the proportion of the overall sampling frame that completed and returned questionnaires) for Population 1 was 17.4% and was 16.0% for Population 2.



Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 3-3. Households selected for inclusion in the sampling frames (Populations 1 and 2).

3.5 Questionnaire Construction and Pretest

The household questionnaire used in our study of diffusion and protective action initiation during the Oroville Dam event was constructed to measure these variables and many others which the research literature has documented to influence both alert/warning diffusion (see Chapter 4) and PAI (see Chapter 5).

The questionnaire was drafted and then pretested on August 14 and 15, 2017 in Salt Lake City, Utah and Harrisburg, Pennsylvania. The pretest was administered to 13 respondents who were selected so that they varied in socio-demographic characteristics as follows. Age varied between 19 and 90 with a mean of 46 years old. Level of education varied between high school graduate to graduate degree and were distributed as follows: one high school graduate, five completed some college but did not have a degree, five college graduates with a degree, and two completed a graduate degree. Six interviewees used in the pre-test were female while seven were male. It took respondents between 15 and 20 minutes to complete the questionnaire. This amount of time to complete a questionnaire would not deter respondents from participating in the study.

The final revised questionnaire, as it was mailed to respondents, is presented in Appendix 9. Additional related instruments were also prepared. Appendix 8 presents the codebook that was constructed to help guide data analysis. Three additional instruments were prepared for possible future use by the USACE. These were a non-formatted version of the Oroville questionnaire (see Appendix 7), a generic public questionnaire to be adapted to future events that might be studied (see Appendix 10), and a generic public codebook also to be adapted to future study events (see Appendix 11).

3.6 Questionnaire Clearance

The survey questionnaire was submitted to the Office of Management and Budget in August of 2017 for review and approval before the questionnaire was mailed to respondents. We were informed by the USACE on October 7, 2017 that we could proceed to distribute questionnaires to the study population since OMB missed the questionnaire review deadline.

The questionnaire was also submitted to the Internal Review Board (IRB) at California State University, Fullerton (CSUF) on September 5, 2017 for review and approval. The CSUF IRB was used for this review since the survey firm we hired to conduct the survey was housed there. Approval was received on September 20, 2017.

The study’s Principal Investigators, Drs. Sorensen and Mileti, were required by the California State University Fullerton Internal Review Board to take and pass a test on survey research ethics involving human subjects for final IRB approval. They completed and passed the examination in October 2017.

3.7 Questionnaire Administration

Each potential survey respondent in both study populations was mailed a packet on October 12, 2017 that contained the survey questionnaire; a cover letter explaining the purpose of the study (which also provided informed consent information and noted that a $15 incentive was available for completing the survey); a unique identifier for tracking survey completion; and a self-addressed, stamped envelope so the respondent could mail the sample survey firm free of charge. About two weeks after the initial questionnaire was mailed, postcards were sent out on November 3, 2017 to non-completers reminding them to complete the questionnaires they had already received. The contents of the reminder postcard are shown in Figure 3-4.

In a final effort to increase respondent participation in the survey, two weeks after this postcard was sent out, an additional copy of the questionnaire was sent on November 16, 2017 to those who had not returned the first copy of the questionnaire. Completed returned questionnaires were received for weeks thereafter. January 9, 2018 was selected as the cutoff date to process data from returned questionnaires since sample sizes were of a sufficient number for sample findings to be generalized to their respective populations.

PUBLIC QUESTIONNAIRE REMINDER POSTCARD

A questionnaire was mailed to you several weeks ago about your experience with the February 2017 Oroville Dam warnings and your response to them. Your name was randomly drawn from all households who may have received the warnings in Butte, Sutter, and Yuba counties.

The first 800 people who complete and return the questionnaire will receive a $15 gift card!

If you have already completed and returned the questionnaire, please accept our sincere thanks. If not, please do so today. A prepaid envelope was included in your survey package to use in returning your completed survey. We are especially grateful for your response because it is only by asking people like you to share your experience that we can understand how to improve emergency warnings here in California as well as the entire nation.

If you did not receive a questionnaire, or it was misplaced, please call us at 657-278-7691 and we will get another one in the mail to you today.

Laura Gil-Trejo, MPH, MA
Director, Social Science Research Center
California State University, Fullerton

Figure 3-4. Reminder postcard distributed to people included in survey samples.

3.8 Sample Sizes and Confidence Levels

In all, 435 residents from Population 1 completed and returned survey questionnaires. Based on the population size of 43,293 people, the margin of error of the sample for Population 1 was ±2.34 points at the 95% confidence level. The sampling fraction for Population 1 was 1.0% (435 completed surveys/43,293 residents).

A total of 400 residents completed and returned the questionnaire from Population 2. Based on the Population 2 size of 133,805 people, the margin of error of the sample for Population 2 is ±2.45 points at the 95% confidence level. The sampling fraction for Population 2 is 0.3% (400 completed surveys/133,805 residents).

The response rate for Population 1 was 17.4%, considering 435 completed questionnaires, with 452 returned as undeliverable, five ineligible respondents, four refusals, and 1,604 questionnaires presumed to be delivered to households in the frame. We used the American Association for Public Opinion Research (AAPOR) Response Rate Calculation 3 (RR3). The RR3 formula is:

$$Rate = \frac{C}{(C+I)+(R+N)+eU} \tag{1}$$

Where:
C = complete surveys
I = incomplete surveys
R = eligible refusals
N = other eligible non-complete records
e = estimate of eligibility
U = records with unknown eligibility

The response rate for Population 2 was 16.0%, considering 400 completed and returned questionnaires, 273 returned as undeliverable, and 1,827 surveys presumed to be delivered to households in the frame.

Figure 3-5 displays the geographic distribution of survey completers and non-completers within the sampling frame. As shown, survey completion was relatively evenly distributed throughout the area. However, there were some small pockets of non-completers, particularly at locations very distant from the dam. Examples of such areas are Wheatland, Rio Oso, and East Nicolaus.

3.9 Assessing for Bias in the Samples

Although best efforts were made to collect survey samples that were representative of the populations being studied, biases were detected in both samples in that they differed from the populations[1] they represented on a few key demographic factors. Results for Population 1 regarding race, income level, and level of education is presented followed by the same results for Population 2.

---

[1] All population data are for the block groups included in the sampling frame. American Community Survey 5-year Estimates from the 2012-2016 period were used.

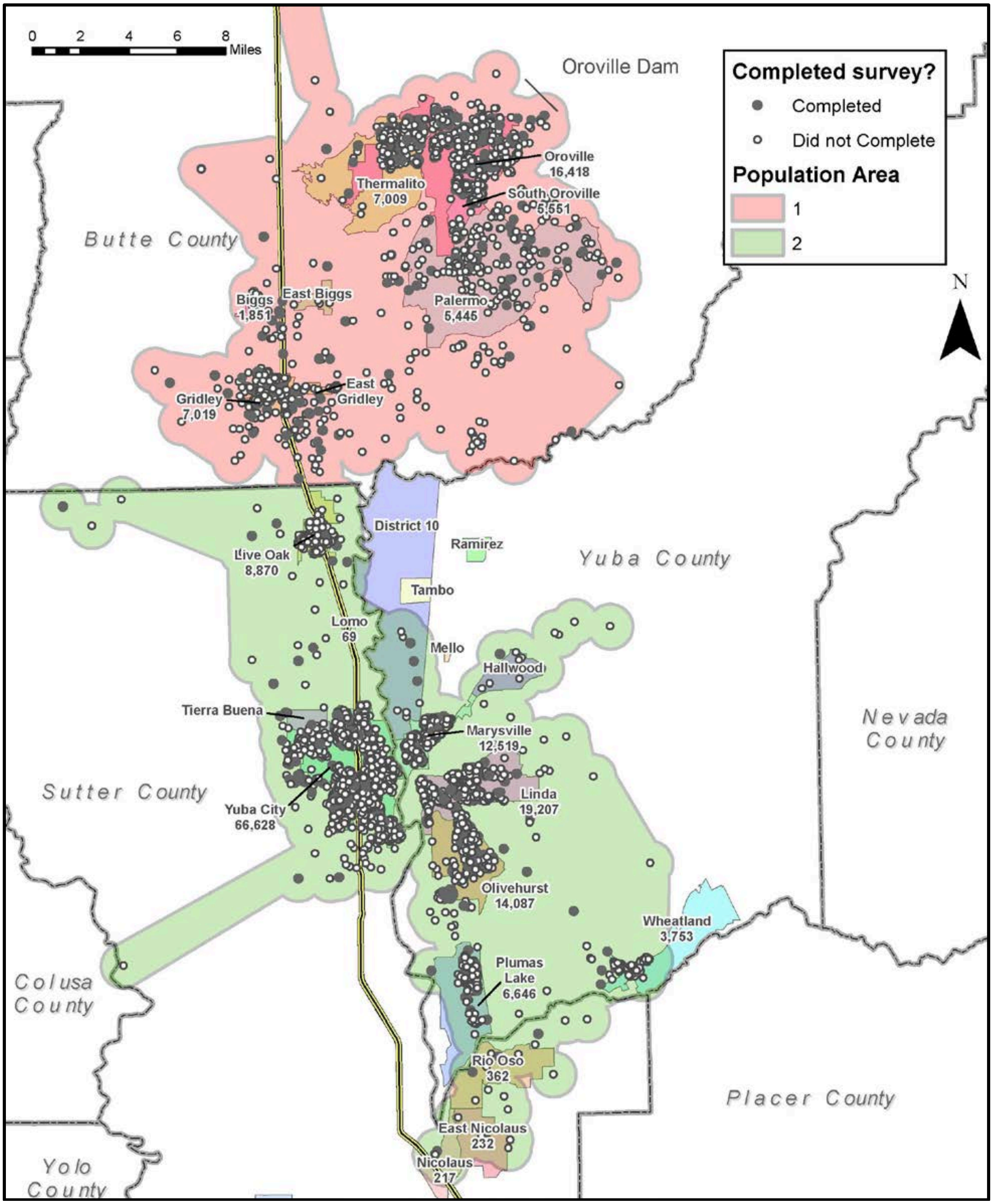


Figure 3-5. Comparison of sampling frames and questionnaire completers in both populations.

3.9.1 Race/Ethnicity (Population 1)

Table 3-1 displays the racial/ethnic distribution of Population 1 and of the survey sample for that group.[2] As shown, White respondents were highly overrepresented in the study sample (83.3%) as compared to the population (59.7%), while several other ethnic groups were under-represented. For example, Hispanics/Latinos made up less than half the proportion of the study sample (8.5%) in relation to the population (21.3%). Similarly, a much larger percentage of Population 1 was Asian (8.3%) than in the study sample collected (1.9%). However, American Indians/Alaskan Natives are overrepresented in the sample (3.3%) compared to the population (1.2%) by a factor of nearly three. Other differences are shown in the table.

Table 3-1. Comparison of study sample and population by race/ethnicity for Population 1.

Race/Ethnicity	Percent in Study Sample	Percent in Population
White	83.3%	59.7%
Hispanic or Latino	8.5%	21.3%
Black or African American	1.2%	2.1%
Asian	1.9%	8.3%
Native Hawaiian or other Pacific Islander	0.2%	0.2%
American Indian or Alaskan Native	3.3%	1.2%
Other	1.7%	6.4%
Total	**100.0%**	**100.0%**

3.9.2 Household Income (Population 1)

For the Population 1 sample, household income was collected using the groups shown in Table 3-2.[3] Giving the first category (Less than $15,000) a value of 1, the second category ($15,000 to $24,999) a value of 2, and so on, a median value was calculated including all valid responses in the survey sample. This value was 3, roughly corresponding with the category highlighted in blue in the table ($25,000 to $34,999). For the population, a median household income was available for each block group in Population 1. These median incomes were averaged (also using the median), yielding a value of $39,049, slightly higher than the median of the study sample.

---

[2] Eleven individuals in the survey sample from Population 1 did not provide information on their race/ethnicity.

[3] Fifty-six respondents from Population 1 did not provide information on household income.

Table 3-2. Sample household income distribution (Population 1).

Median Household Income	Percent in Study Sample
Less than $15,000	17.7%
$15,000 to $24,999	18.2%
$25,000 to $34,999	15.3%
$35,000 to $49,999	13.7%
$50,000 to $74,999	16.6%
$75,000 to $99,999	6.6%
$100,000 to $149,999	5.8%
$150,000 to $199,999	3.7%
$200,000 or more	2.4%
Total	**100.0%**

3.9.3 Education (Population 1)

Table 3-3 shows the level of education for Population 1 respondents over 25 who completed the survey and for the general population.[4] Overall, the level of education of those who completed the survey was higher than that of the population. For example, while more than a third (34.5%) of those in Population 1 had less than a high school diploma, only 10.2% of those in the study sample indicated this level of education. The proportion in each of the remaining education categories was higher in the study sample than the population.

Table 3-3. Comparison of study sample and population by education level for individuals 25 years and older (Population 1).

Education Level	Percent in Study Sample	Percent in Population
Less than a HS Diploma	10.2%	34.5%
HS Diploma or Equivalent[5]	68.4%	47.2%
Bachelor's Degree	14.2%	13.3%
Graduate Degree	7.2%	5.0%
Total	**100.0%**	**100.0%**

---

[4] Education data were only available for those individuals 25 years of age or older. Five individuals from Population 1 who were between 18 and 24 are excluded from these analyses.

[5] For the study sample data, "HS Diploma or Equivalent" includes the following responses from the survey: "HS diploma or equivalent," "some college but no degree," and "associate degree."

3.9.4 Race/Ethnicity (Population 2)

The racial/ethnic distribution of Population 2 versus the survey sample for that group is illustrated in Table 3-4.[6] Like Population 1, White respondents were highly overrepresented in the study sample, comprising more than three quarters of that group (75.4%) but less than half (49.0%) of the population. Again, other racial/ethnic groups were underrepresented to varying degrees. For example, Hispanic/Latino individuals encompassed nearly one third (30.3%) of Population 2 but were only 10.5% of the study sample. Additional differences are displayed in Table 3-4.

Table 3-4. Comparison of study sample and population by race/ethnicity (Population 2).

Race/Ethnicity	Percent in Study Sample	Percent in Population
White	75.4%	49.0%
Hispanic or Latino	10.5%	30.3%
Black or African American	2.3%	2.4%
Asian	5.6%	12.4%
Native Hawaiian or other Pacific Islander	0.8%	0.4%
American Indian or Alaskan Native	1.8%	0.8%
Other	3.6%	4.7%
Total	**100.0%**	**100.0%**

3.9.5 Household Income (Population 2)

For Population 2, household income data was treated in the same way as Population 1. Table 3-5 shows the household income distribution of the study sample. The median group, corresponding with a value of 5 is highlighted in blue (using the same technique as Population 1).[7] The median value of all median household incomes from each block group was calculated, producing a value of $39,049. Unlike Population 1, the median household income of the Population 2 study sample was slightly higher than the median of the population.

---

[6] Nine individuals from the survey sample for Population 2 did not provide information on their race/ethnicity.

[7] Twenty-eight individuals from Population 2 did not provide information on household income.

Table 3-5. Sample household income distribution (Population 2).

Median Household Income	Percent in Study Sample
Less than $15,000	9.1%
$15,000 to $24,999	8.6%
$25,000 to $34,999	13.4%
$35,000 to $49,999	13.4%
$50,000 to $74,999	19.9%
$75,000 to $99,999	13.2%
$100,000 to $149,999	13.4%
$150,000 to $199,999	5.4%
$200,000 or more	3.5%
Total	**100.0%**

3.9.6 Education (Population 2)

Table 3-6 shows the level of education for Population 2 respondents over 25 who completed the survey and for the general population.[8] As shown, 36.2% of Population 2 members had less than a high school diploma, but only 5.9% of those in the study sample did. Conversely, more than two thirds of those in the study sample (67.1%) possessed a high school diploma or equivalent, compared to only a third (36.4%) of those in the population. While 15.9% of those from Population 2 who completed study had bachelor’s degrees, nearly one in five (19.0%) residents 25 years and older in the population did. Finally, the proportion of survey completers with a graduate degree (11.1%) was slightly higher than in the overall population (8.4%).

Table 3-6. Comparison of study sample and population by education level for individuals 25 years and older (Population 2).

Education Level	Percent in Study Sample	Percent in Population
Less than a HS Diploma	5.9%	36.2%
HS Diploma or Equivalent	67.1%	36.4%
Bachelor's Degree	15.9%	19.0%
Graduate Degree	11.1%	8.4%
Total	**100.0%**	**100.0%**

---

[8] Education data were only available for those individuals 25 years of age or older. Eight individuals from Population 2 who were between 18 and 24 are excluded from these analyses.

3.9.7 Conclusions about Sample Bias

The biases discovered in the samples are not surprising and are often found in sample survey research. Whites and more educated people were more likely to complete and return our questionnaire than non-whites and less educated people. Additionally, for Population 1, median household income was higher in the population than the sample, while for Population 2 median household income was lower in the population than the sample. Race, level of education, and income are all either covariates or general indicators of social class; hence, the sample biases we discovered suggest that consideration should be given to controlling for respondent social class if more detailed data analyses are ever conducted beyond the analyses presented in this report.

3.10 Overview and Summary

The sampling frame was comprised of 5,000 households with 2,500 households from both Populations 1 and 2. A total of 835 completed questionnaires were obtained across both populations and the 145 Census block groups included in the sampling frame. Of these completed questionnaires, 435 were from Butte County (Population 1) yielding a 1% sampling fraction, and 400 were from Sutter and Yuba Counties (Population 2) for a 0.3% sampling fraction. The proportion of the frame that returned questionnaires of response rate (AAPOR RR3) was 17.4% for Population 1 and 16.0% for Population 2.

The margin of error for generalizing from the samples to the populations for Population 1 was ±2.34 points at the 95% Confidence Level, based on population of 43,293. For Population 2, it was ±2.45 points at the 95% confidence level, based on population of 133,805. These margins of error are well within standard acceptable levels to generalize findings from a survey sample to its respective population.

There was an even geographical distribution of households who completed and returned questionnaires with one exception. There were small pockets of households that did not return questionnaires in areas most distant from the dam.

There were predictable biases contained in the samples. White and more educated respondents were overrepresented in both samples. Additionally, for Population 1, median household income was higher in the population than the sample, while for Population 2 median household income was lower in the population than the sample.

4.0 FINDINGS FOR WARNING DIFFUSION DELAY

4.1 Purpose

In this chapter, we examine first warning diffusion in the two study populations. We define the concept of warning diffusion, examine the factors that influence warning diffusion delay, present the descriptive findings from the survey conducted on the event, construct diffusion curves, and examine the relationship between those empirical curves and models of warning diffusion. Implications for future data collection are discussed and recommendations are made about future data analysis.

4.2 Warning Diffusion Delay Defined

First alert diffusion has been defined as the percentage of the total at-risk population targeted as the recipients of the first alert message or signal that receive it over time (Sorensen and Mileti, 2014b). In events with no or little forewarning, the official first warning may be the predominant way in which the public receives the initial communication about the potential for an event. This was not the case in this study. In events characterized by elevated risk levels and extensive news coverage prior to the official warning, the first "official warning" containing protective action instructions may not be perceived by the public as the first warning. This was the type of warning situation during the Oroville event. Risk information was communicated to the public about problems at the Oroville Dam beginning on February 7th, five days prior to the "official warning" (see Chapter 1). This created a challenge for interpreting the results of the public survey and using the results to assess the implications for diffusion curve modeling efforts. However, analyzing the data from this event furthered our conceptual understanding of diffusion.

4.3 Factors that Influence Warning Diffusion Delay

Mixes of different factors influence first alert diffusion time. These factors and their relative importance are catalogued in Table 4-1. They have been divided into the factor classes of sending and receiving the first alert. A detailed discussion of these factors can be found in Sorensen and Mileti, 2014b. Table 4-1 also shows which questions from the public questionnaire were used to measure these factors for this study (see Appendix 9).

Table 4-1. Factors that influence first alert/warning diffusion time.

FACTOR	IMPORTANCE	MEASURED BY *
Sending the First Alert/Warning		
Channels - Types of Technologies	High	Q9, 10
Channels - Disruption to Infrastructure	Low	Not Measured
Channels - Number and Mix of Channels	High	Q21, 22
Frequency of Distribution	High	Q19
Informal Notification	Moderate	Q9, 10, 21, 22
Environmental and Social Cues	Low	Not Measured
Receiving the First Alert Warning		
Activity -Task	Moderate	Q11
Activity - Location & Proximity to Hazard	Moderate	Q12
Activity - Time of Day	High	Q8
Impediments - Sensory (Hearing, Visual)	Moderate	Not Measured
Impediments - Linguistic and Cultural	Low	Not Measured
Resources - Access to Technology	Moderate	Q37 (indirect)
Social Media Participation	Low	Not Measured
Socio-Economic Status	Moderate	Q34, 36, 37, 38

**See Appendix 9 for specific questions used.*

4.4 Measurement

4.4.1 Measurement of Timing of Warning

Warning receipt and time of receipt was measured by using the following instructions and questions:

THE NEXT QUESTIONS ARE ABOUT THE “FIRST EVACUATION MESSAGE” YOU RECEIVED ON OR AFTER FEBRUARY 12, 2017. BY MESSAGE WE MEAN INFORMATION FROM GOVERNMENT, MEDIA, OR PERSONAL CONTACTS SUCH AS FRIENDS, RELATIVES, OR CO-WORKERS.

IF YOU DID NOT RECEIVE AN EVACUATION MESSAGE, SKIP TO QUESTION 25

Q7. Think about the *first* evacuation message you received aimed at people in the area in which you were located. What day did you get that message? **(CIRCLE ONE)**

1 = SUNDAY, FEBRUARY 12
2 = MONDAY, FEBRUARY 13
9 = OTHER **(SPECIFY: ____)**

Q8. Think about the *first* evacuation message you received aimed at people in the area in which you were located. What time did you get that message?
(FILL IN BELOW WITH THE BEST ESTIMATE YOU CAN MAKE)
HOUR _________ MINUTE _________ AM or PM _________

4.4.2 Measurement of Factors Affecting Warning Receipt

Factors affecting warning receipt that were measured in the public survey are identified in Table 4-1 with reference to the questions in the survey associated with each factor. Not all factors associated with the timing of warning receipt were measured because understanding how some of these factors impacted timing was not a central focus of the study. What we did measure regarding sender factors were channel (Q9) and source (Q10) of the first warning, the channels (Q21) and sources (Q22) of subsequent warnings, the number of subsequent warnings received (Q19), and informal notification (Q9, 10, 21, and 22). Receiver characteristics measured were activity by task (Q11), activity by location (Q12), time of day (Q8), resources (income) (Q37) and socioeconomic status factors including ethnicity (Q 34), education (Q36), income (Q37), and occupation (Q38). Other demographic factors measured included gender (Q33) and age (Q35).

4.5 Descriptive Findings

4.5.1 First Warning Receipt (Populations 1 and 2)

Overall, 86.4% of Population 1 and 89.0% of Population 2 received a warning. This was measured by the percentage of people who answered rather than skipped questions 7 and 8. We refer to this group as the "warned population." In both populations, approximately 90% of all first warnings were reported to have been received on Sunday, February 12th.

4.5.2 Channels of First Warning (Populations 1 and 2)

Table 4-2 summarizes the channel by which the warned populations reported to have received their first warning message. No single channel dominated as the primary first warning vehicle in Population 1. The two channels reaching the highest number of people in that population were text messages on a mobile device (18.6%) and television (18.1%). These were followed by a cell phone call from another person (13.9%), face-to-face communications (11.3%), and a recorded message on a cell phone (10.2%). All other channels were lower than 10%. All forms of social media only accounted for 2.9% of the first warning message received. Outdoor sirens were cited by a small number of respondents, and since there were no fixed sirens used in the warning, we concluded that these were emergency sirens on vehicles conducting route alerts.

In Population 2, a single channel (television) dominated as the first warning vehicle (30.4%). This was followed by face-to-face communications (13.7%), a recorded message on a cell phone (12.0%), and a cell phone call from another person (10.9%). Again, social media only accounted for a very low percentage (3.4%) of the first warning message received.

Table 4-2. Channels of first warning message received.

First Warning Message Channel	Population 1 *% of Pop. (N)*	Population 2 *% of Pop. (N)*
Landline telephone with a recorded message	5.5% (21)	8.9% (32)
Landline telephone with a live person	6.6% (25)	2.2% (8)
Cell phone or other mobile communication device with a recorded message	10.2% (39)	12.0% (43)
Cellphone or other mobile communication device with a live person	13.9% (53)	10.9% (39)
Text message – On a mobile communication device such as a cell phone	18.6% (71)	8.4% (30)
Internet – An email	0.3% (1)	0.3% (1)
Internet – Social media such as Twitter or Facebook	2.9% (11)	3.4% (12)
Internet – Website	0.3% (1)	0.6% (2)
Face-to-face from an authority	3.4% (13)	1.7% (6)
Face-to-face from another person, for example friend or family member	11.3% (43)	13.7% (49)
An authority in the street with a loud speaker	2.1% (8)	0.8% (3)
Television	18.1% (69)	30.4% (109)
Radio	2.9% (11)	3.9% (14)
Tone alert National Weather Service radio	0.5% (2)	1.1% (4)
Outdoor warning siren	1.6% (6)	0.0% (0)
Other	1.8% (7)	1.7% (6)
Total (People who answered question 9)	**100% (381)**	**100% (358)**

4.5.3 Sources of First Warning (Populations 1 and 2)

Whereas channel is how of the warning receipt, source is the “who” of the message originator. Table 4-3 contains the source of the first message received for both populations. In Population 1, the most frequently cited source is from a family member or other relative (19.7%), followed by the Butte County Sheriff (18.9%) and a broadcaster of some type (15.4%). Neighbors or friends accounted for another 13.8% of the messages. In Population 2, broadcasters were the most frequently cited source (29.9%) followed by two informal sources including family members or relatives (22.3%) and neighbors or friends (12.6%). Unlike Population 1, law enforcement played a relatively minor role as the source of the first message.

Table 4-3. Sources of first warning message received.

First Warning Message Source	Population 1 *% of Pop. (N)*	Population 2 *% of Pop. (N)*
Local police	7.7% (29)	3.4% (12)
Local fire department	1.1% (4)	0.3% (1)
Governor's office of emergency services	5.1% (19)	6.7% (24)
CAL Fire	1.1% (4)	0.0% (0)
Butte County Sheriff	18.9% (71)	1.1% (4)
Sutter County Sheriff	0.0% (0)	3.1% (11)
Yuba County Sheriff	0.0% (0)	7.0% (25)
Yuba City Officials	0.0% 0	2.8% (10)
California Department of Water Resources (DWR)	1.9% (7)	1.7% (6)
National Weather Service	3.7% (14)	1.4% (5)
Family member or other relative	19.7% (74)	22.3% (80)
Neighbor or friend	13.8% (52)	12.6% (45)
Employer	0.8% (3)	0.8% (3)
Co-worker	2.1% (8)	2.0% (7)
TV, radio, or internet broadcaster	15.4% (58)	29.9% (107)
Other	8.8% (33)	5.0% (18)
Total (People who answered question 10)	**100.0% (376)**	**100.0% (358)**

4.5.4 Number of Subsequent Messages Received (Populations 1 and 2)

On average, a respondent received a mean of 1.7 additional messages following the first message in Population 1 and 2.55 in Population 2. Around 40% only received the first message and reported receiving no subsequent messages in Population 1 while that dropped to 28% for Population 2. This likely reflected that Population 1 needed to respond to warning much more rapidly than members of Population 2.

Table 4-4 summarizes the mean number of subsequent messages received based on the channel of first receipt for both populations. The table confirms previous work that suggests that people received fewer subsequent warning when the initial warning comes from personal communications and official channels. People tend to act more quickly in response to such channels and have less time to receive additional information. Higher levels of subsequent warnings are associated with non-personal sources and channels that provide limited information such as broadcast media, social media, and text messages. The table also shows exceptions to these general findings as in the case of police with loudspeakers being associated with a high level of subsequent warning in Population 1.

Table 4-4. **Mean number of subsequent messages received by respondents based on the channel over which they received the first warning message.**

Channel of First Warning Message	Mean Number of Subsequent Messages (Population 1)	Mean Number of Subsequent Messages (Population 2)
Landline telephone with a recorded message	0.89	1.69
Landline telephone with a live person	1.52	0.88
Cell phone or other mobile communication device with a recorded message	0.81	1.90
Cellphone or other mobile communication device with a live person	1.02	3.08
Text message – On a mobile communication device such as a cell phone	1.79	3.40
Internet – An email	1.00*	2.00*
Internet – Social media such as Twitter or Facebook	3.27	1.30
Internet – Website	1.00*	2.00*
Face-to-face from an authority	0.69	0.50
Face-to-face from another person, for example friend or family member	1.32	1.5
An authority in the street with a loud speaker	2.38	3.67*
Television	2.88	3.43
Radio	3.00	2.75
Tone alert National Weather Service radio	0.00*	6.75*
Outdoor warning siren	0.33	N/A
Other	2.67	0.67

**Less than five observations to compute mean.*

4.5.5 Location of People When First Warning Was Received (Populations 1 and 2)

Most people in both our study populations were at home when they received the warning, according to the data presented in Table 4-5. A few were in a vehicle driving or at a friend's or relative's place. Not very many were working, shopping or engaged in recreational activities.

Table 4-5. Where people were/what they were doing when they received their first warning message.

Location/Activity when First Warning Was Received	Population 1 *% of Pop. (N)*	Population 2 *% of Pop. (N)*
At home	75.4% (288)	77.0% (278)
At work	4.7% (18)	2.8% (10)
Shopping at store	2.4% (9)	2.2% (8)
Driving a vehicle	6.0% (23)	5.3% (19)
Passenger in a vehicle	0.5% (2)	1.4% (5)
Engaged in an outdoor recreational activity	1.8% (7)	0.8% (3)
Engaged in an indoor recreational activity	1.3% (5)	2.2% (8)
At a relative's or friend's place	4.7% (18)	4.4% (16)
Other	3.1% (12)	3.9% (14)
Total (People who answered question 11)	**100.0% (382)**	**100.0% (361)**

4.5.6 Role of Modern Technology

To more fully assess the role that newer and more modern technologies have on the diffusion of warnings, channels were categorized into three basic types:

- <u>Modern Channels</u>: These include land line telephone with a recorded message, cell phone or other mobile communication device with a recorded message, text message – on a mobile communication device such as a cell phone (if it came from official source), internet – an email, internet – social media such as twitter or Facebook, or internet – website.
- <u>Traditional Channels</u>: These include face-to-face from an authority, an authority in the street with a loudspeaker, television, radio, tone alert National Weather Service Radio, or outdoor warning siren.
- <u>Informal Channels</u>: These include land line telephone with a live person, cell phone or other mobile communication device with a live person, text message – on a mobile communication device such as a cell phone (if it came from non-official source), or face-to-face from another person, for example friend or family member.

Table 4-6 shows the distribution of the receipt of the first message by the three channel types for both populations. The total population in the table are those respondents who identified both the channel and source of the first message and excludes those who answered “other” to either question. In Population 1, informal channels were the most prevalent source of first warning (36.6%), closely followed by modern technologies (34.2%), with traditional technologies warning the lowest percentage (29.2%). If we view these as percent of the total population, the percentages are informal (23.7%), modern (22.1%), and traditional (18.9%).

In Population 2, we see a different picture with traditional technologies (36.4%) followed by informal (32.0%) and modern (31.6%). There is no single reason why the distributions for the two populations differ. It is likely a combination of differing risk levels, amount of time to take action, warning command and control systems, distribution technologies, and economic and demographic characteristics of the two populations.

Table 4-6. Receipt of first warning message by dissemination channel category.

Channel Category	Population 1 % of pop. (N)	Population 2 % of pop. (N)
Traditional	29.2% (82)	36.4% (99)
Modern	34.2% (96)	31.6% (86)
Informal	36.6% (103)	32.0% (87)
Total	100% (281)	100% (272)

4.6 Diffusion Delay Curves for the Oroville Event

4.6.1 Curve Generation Method

The first warning diffusion curves for both Populations 1 and 2 were generated based on people's responses to the following question: "Think about the *first* evacuation message you received aimed at people in the area in which you were located. What time did you get that message?" This was coded as minutes past midnight. Rather than doing a curve for the entire time period, we eliminated the people who reported receiving their first warning before and after Sunday to focus on the day the first official warnings were issued and most people reported receiving their first warning message (about 90% of warned population in Populations 1 and 2). Frequencies were calculated for each time, and a cumulative sum of the frequencies by time was calculated. These were converted into the percent of the total population (including those who reported that did not receive a warning or that they received their first warning before or after the 12th), and, for the percent of the sample that received a first warning on Sunday.

4.6.2 Whole Population Diffusion Curves (Populations 1 and 2)

Figure 4-1 shows the timing of the warning diffusion on Sunday for the Butte County population. It is significant to note that slightly over 50% of the total population indicated they received the warning prior to the Sheriff's official warning at 4:21 PM. This can be attributed to a combination of several factors listed below in descending order of likely influence:

- Pre-official Warning Risk Information: The first official warning came after a mix of other information about risks at the dam and the possible need for evacuation to which the public was exposed since February 7th. For example, press releases from the Butte County Sheriff's Office were issued on February 9th and 11th (see Appendix 1) asking residents to prepare for possible evacuation along the Feather River. Furthermore, news coverage of an endangered emergency spillway on the morning of the 12th and interpersonal communications may have been interpreted as a "first message" for the event by some members of the public. This interpretation is largely consistent with the finding that only around 19% of the population indicated their first message was from the Sheriff and around 36% said it was from an informal source such as a relative, friend, or employer.

- Recall Error: Given the long amount of time that elapsed between the event and the survey, people may not have accurately remembered the exact time when they received what they interpreted as their first warning. Thus, the reporting of early times may be partially attributed to recall error.
- Normative Bias: Often in surveys on human behavior, responses are affected by a type of normative bias. Instead of responding about their actual behavior, some people may respond with answers that reflect what they think they should have done. This is not a deliberate act, but one of perception affecting their response to an event in the past. This could have been heightened by the extensive media coverage of the event which was marked by considerable blame assignment and criticism. If this is the case, people may have thought that they were warned earlier than was actually the case.
- Anchoring: Moreover, people anchor to units of time expressed in increments that are rounded off to cognitively available reference points – hours, half hours, 15 minutes and so forth. Therefore, what is a precise minute to the statistician, may be the closest hour or half hour to many respondents. For example, if someone received the warning shortly after the 4:21 PM issuance time, they may have remember receiving it around 4:00 or 4:15. In this case, the curve shows that about 20% of the total population expressed hearing it at 4:00 or 4:15 PM.

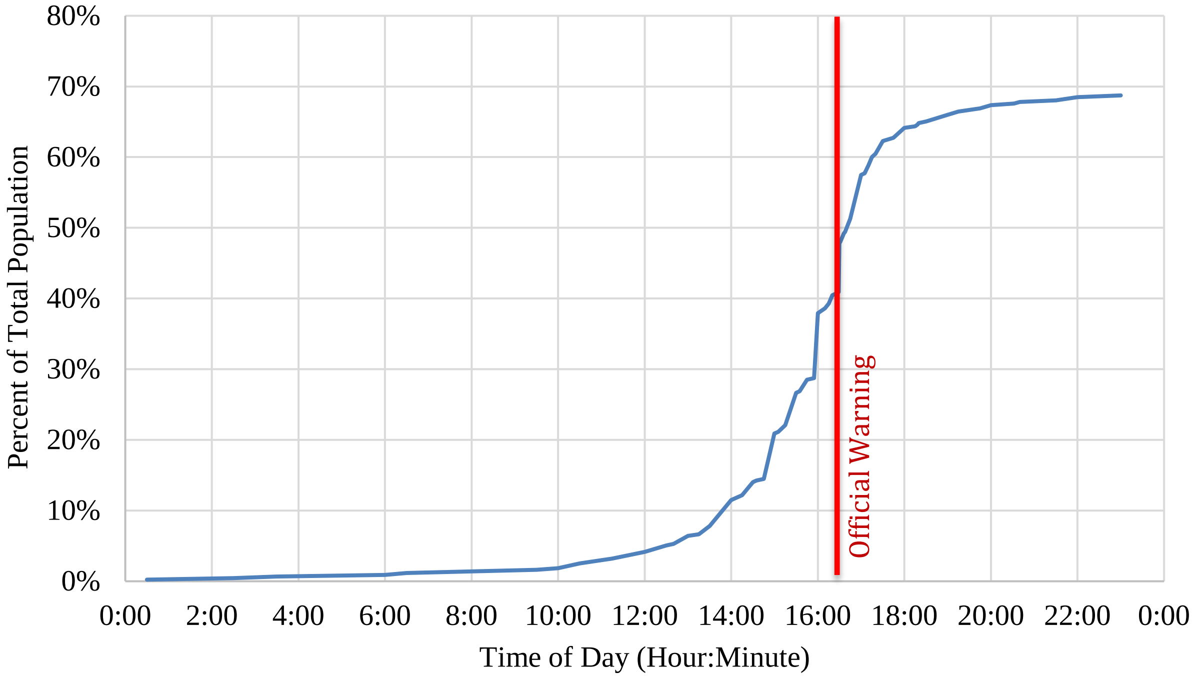


Figure 4-1. Warning diffusion curve for respondents who reported receiving a first warning message on Sunday, February 12 (Population 1).

In Population 2, which was comprised of residents in Sutter and Yuba County, the majority again reported receiving a warning before the first official warning for their counties (Figure 4-2). In addition to the factors discussed for Population 1, which also would have held for Population 2, the wording of the original evacuation warning from Butte County included the term “and areas downstream.” This may have caused people to interpret the original Butte County warning message as including areas in Sutter and Yuba Counties that have historically flooded from high water on the Feather River. Since many reported hearing the warning from news media, there may have been confusion over who was at risk from an emergency spillway failure.

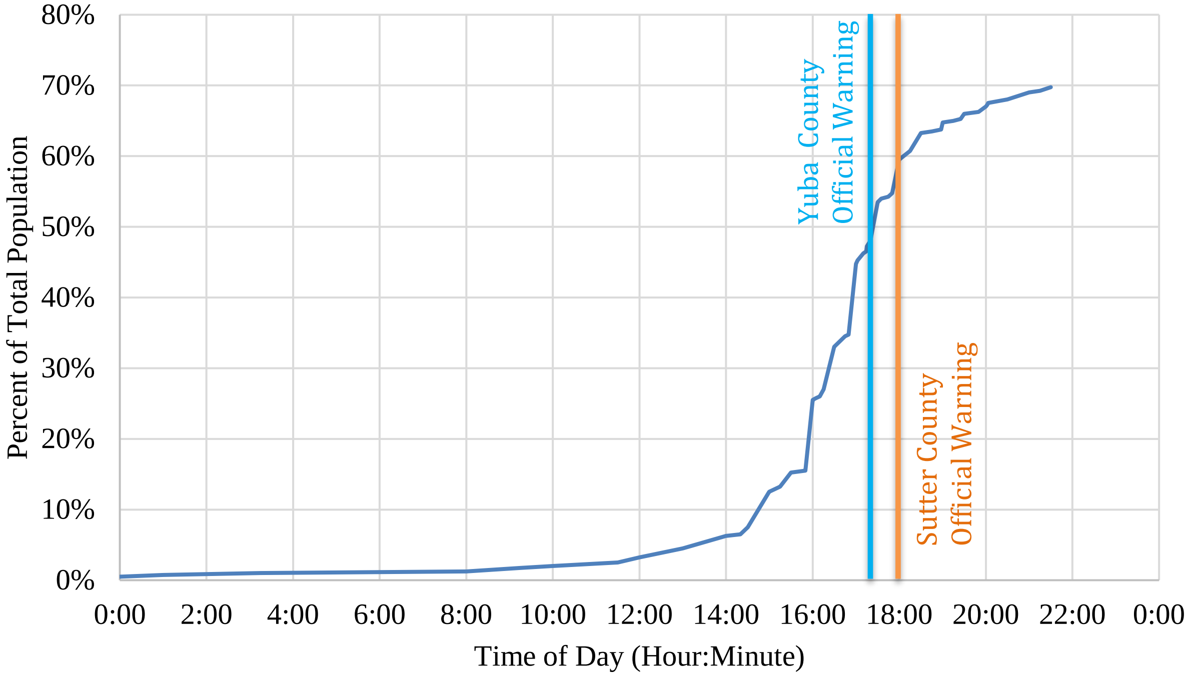


Figure 4-2. Warning diffusion curve for respondents who reported receiving a first warning message on Sunday, February 12 (Population 2).

4.6.3 Diffusion by Channel Category (Populations 1 and 2)

To further explore warning diffusion, we wanted to examine each warning channel individually. Due to the fact that many of the channels had insufficient numbers to generate curves, we used the three categories of channels discussed earlier: Modern, Traditional, and Informal. Figure 4-3 and Figure 4-4 show the diffusion over time for these three channel categories. In these figures, the cumulative percentages and the end point of each curve is the number of people warned on Sunday divided by the total population size (Population 1 = 435 and Population 2 = 400). This provides us with a relatively good measure of the effectiveness of the first message diffusion process for each channel category. Figure 4-3 shows that in Population 1, informal warning channels performed the quickest, closely followed by modern channels, while traditional channels performed the slowest. In Population 2, all three channel categories performed about equally through much of the time history of the diffusion process. Traditional channels provided warning to a greater number of people later in the timeline.

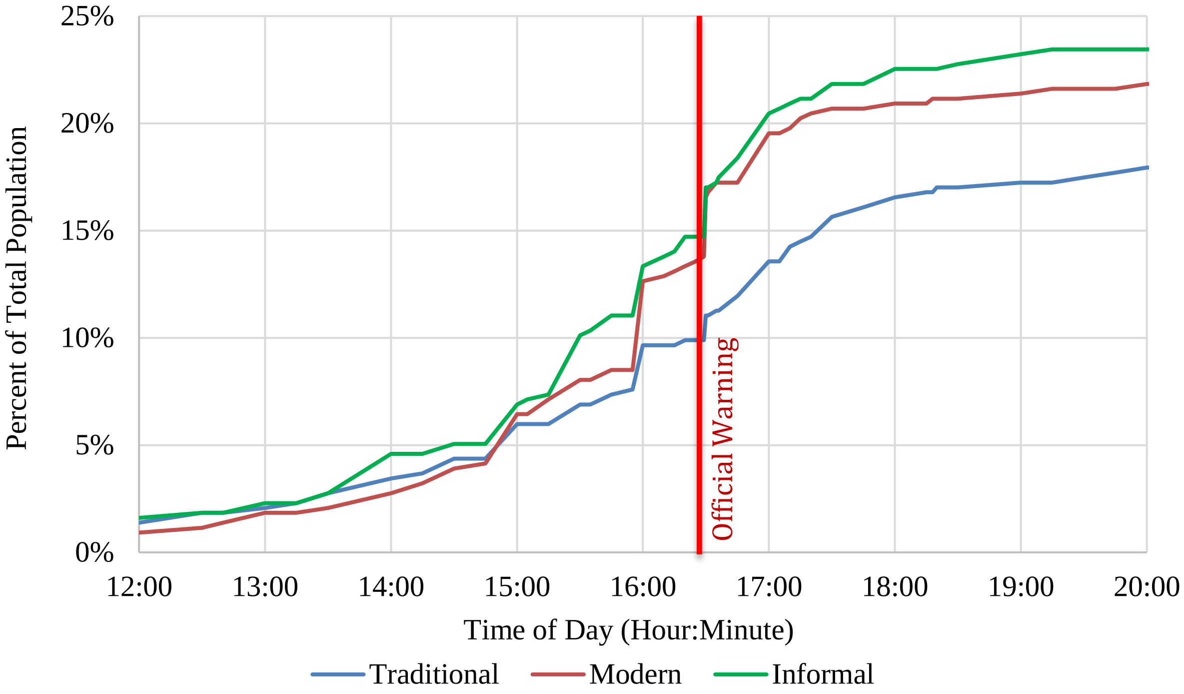


Figure 4-3. First warning diffusion curves for February 12 by message channel category (Population 1).

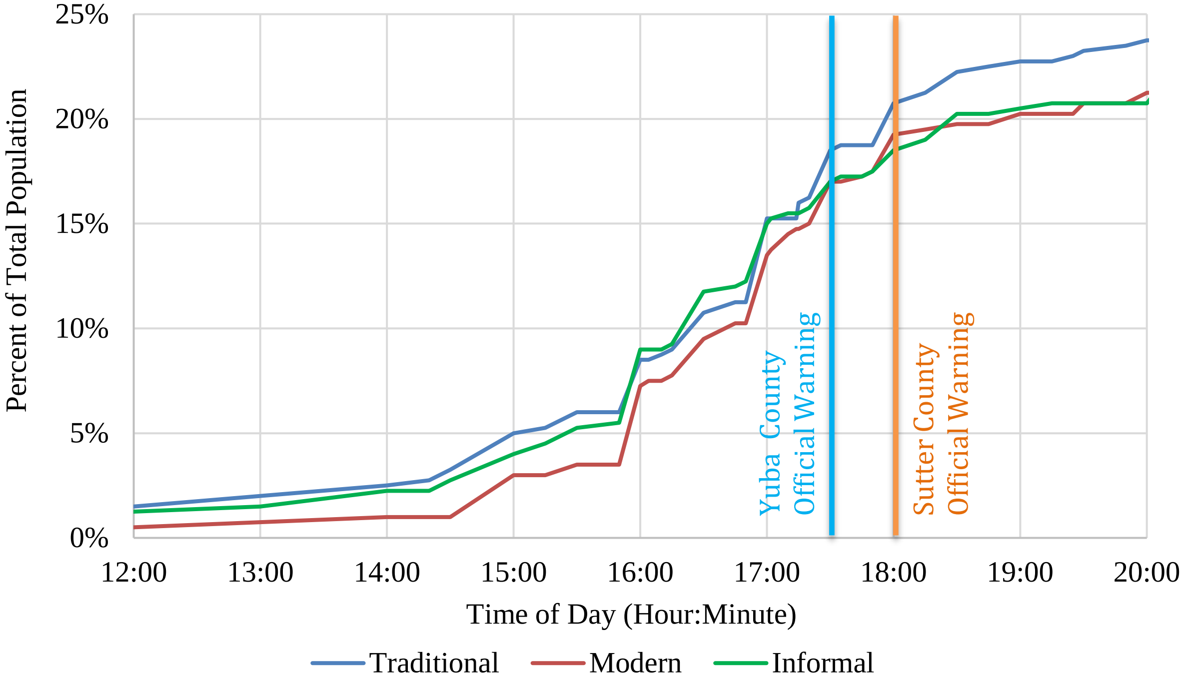


Figure 4-4. First warning diffusion curves for February 12 by message channel category (Population 2).

4.7 Implications for Previously Recommended Curves.

4.7.1 Diffusion Curve Modeling Simulation Method

First warning diffusion is a function of:

- Broadcast or the direct receipt of an official alert or message, and
- Informal or indirect warning from friends, neighbors, co-workers, and relatives.

Broadcast is based on direct alerting from specific dissemination channels. Informal warning is based on:

- Broadcast receipt in that you need to hear an alert or warning to make an informal notification, and
- Cascading informal effects, or the case in which an informal message receipt propagates new informal messages.

Broadcast and informal warning probabilities are dynamic over the period of warning (Rogers and Sorensen, 1988). For example, when sirens are activated, more people will interpret it as an emergency alert after 10 minutes of sounding than after 10 seconds of sounding. The same holds true for other systems such as radio or TV messages. In accordance with Lindell and Perry (2004), the probability of the first warning receipt follows a logistic distribution that can be approximated by a modified Rayleigh probability distribution.

To begin, we will define the effectiveness of the broadcast system in an equation. The broadcast may be made up of many channels at once. Each channel may have different effectiveness factors. For our purposes, the effectiveness of a single broadcast is unchanging (i.e. we have a constant *b* if the system is turned on), but it may not be activated through the entire warning process. The effectiveness of the broadcast system can be defined as the mutual probability of being warned by any system in a given timestep *t* (note that the syntax in the formula described here is a shorthand for mutual probability which does not require as much space as the alternative usual way of writing mutual probability). That equation is as follows.

$$B_t = 1 - \prod_{i=0}^{n} 1 - b_i \tag{2}$$

Where:
n = total number of broadcast systems online at the time t
b_i= effectiveness of a single broadcast system as it applies to the entire unwarned population

Next, we will define the indirect warning effectiveness for any time *t*. C_t is a function of a constant *C* which represents the rate that people pass the message along through means other than the official broadcast. It is factored by (1 - PU_t) since the rate a message is spread is dependent upon how many people have the message:

$$C_t = (1 - PU_t) * C \qquad (3)$$

Finally, to describe the rate of change of people being warned across time *t* for a community, we will use the following equation (4). Observe that as Δt approaches zero the factors B_t and C_t will also approach zero. This represents that the likelihood of warning happening in an instant is very small. Further, the portion of the equation $B_t * C_t$ will approach zero faster than the independent factors. This means that as the timestep approaches zero, the likelihood of being warned by the direct broadcast and the indirect warning will be very small.

$$\frac{\Delta W}{\Delta t} = PU_t * (B_t + C_t - B_t * C_t) \qquad (4)$$

Where:
W = alerted population
t = time
$\frac{\Delta W}{\Delta t}$ = rate of population being alerted per timestep
PU_t= population unwarned for timestep *t*
B_t= effectiveness of the broadcast systems in timestep *t*
C_t= effectiveness of the indirect warning in timestep *t*

This equation represents the rate of change of a population’s first alert receipt across time, which is a function of three main parameters: the effectiveness of the broadcast systems, the effectiveness of the indirect systems, and the population that remains to be alerted.

4.7.2 Historical Recommended Diffusion Curves

In our previous research, we developed four planning curves for warning diffusion based on community warning system characteristics (Sorensen and Mileti, 2014b). For each, a daytime and a nighttime curve was developed. The two community factors used to define the community types were the number of diffusion channels used and the repetitive frequency with which the alert has been rebroadcast over them. Thus, the four community types were defined as follows:

- Type A: Fast Diffusion Curve – Uses multiple channels including modern technologies with both very fast speeds of alert and broad penetration with frequent dissemination. These are supplemented by channels with high message quality.
- Type B: Moderately Fast Diffusion Curve – Uses multiple channels but not all the latest modern technologies with modest repetitive distribution of the message.
- Type C: Moderate Diffusion Curve – Uses mix of traditional channels but not modern technology with modest repetitive distribution of the message.
- Type D: Slow Diffusion Curve - Uses limited channels with single dissemination.

The parameter values provided in Table 4-7 are used in the simulation model. The results of the eight simulations are shown in Figure 4-5 which shows the estimated proportion receiving a first warning over time.

Table 4-7. B_t and C_t values used in calculating the planning curves for warning diffusion. *

	Curve Type							
	A		**B**		**C**		**D**	
Time	Day	Night	Day	Night	Day	Night	Day	Night
B_t	5	10	50	70	100	120	150	180
C_t	0.1	0.05	0.08	0.06	0.06	0.05	0.04	0.02

**B_t represents the speed of the direct broadcast technologies and C_t the relative probability of informal notification.*

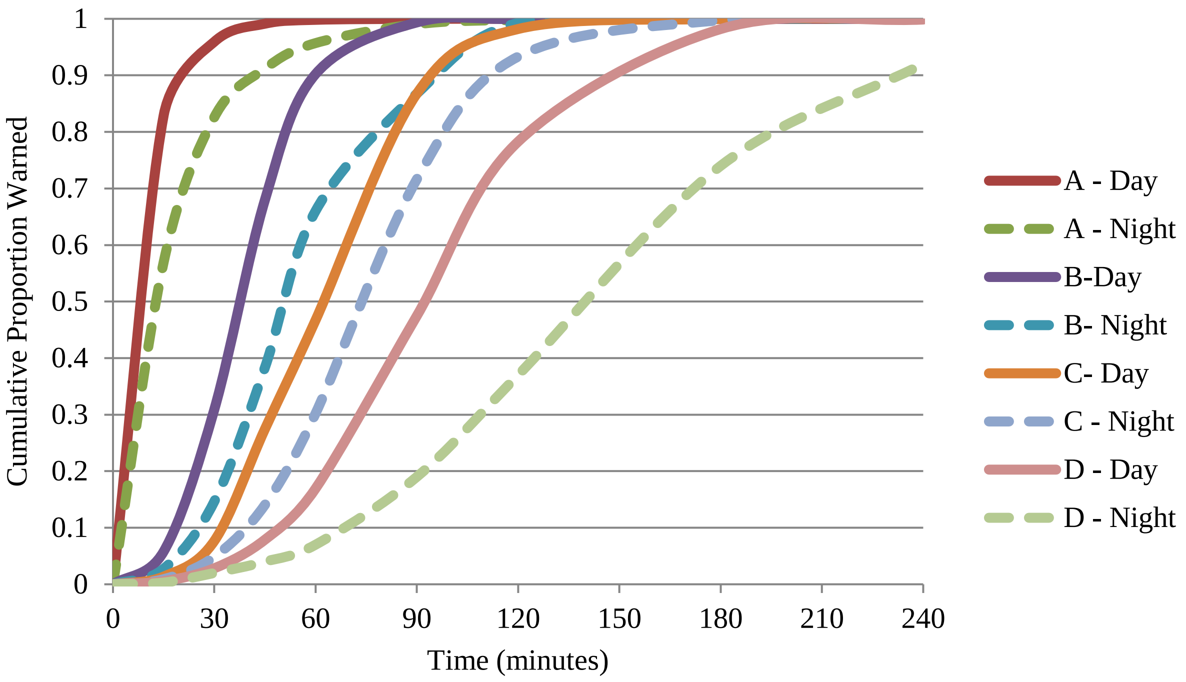


Figure 4-5. Planning curves for warning diffusion.

4.7.3 Modeling the Oroville Empirical Curves.

Because the earlier work on diffusion curves considered only communities in close proximity to the hazard, we only included Population 1 in our current model comparison efforts. Our earlier work simulated warning diffusion for a rapidly unfolding event with little forewarning. The time frame for the diffusion was a four-hour period. This was based on previous research on warning for analogous events that represented a rapid onset event that was occurring or had already occurred. Nevertheless, our first approach was to use the previously developed model to simulate the Oroville event.

Figure 4-6 shows the result of a simulation that used the previously developed model to fit the empirical data and closely approximate the level of informal warning. It clearly underestimates early warning. It closely estimates the proportion of direct and informal warning. A major problem with this simulation is that the model coefficients differ greatly from our planning curves. We concluded that the primary reason for this is that the time scales of the Oroville Dam event and our planning models were not similar. The planning curves were based on a 4-hour event duration while for the Oroville Dam event, the vast majority of warnings that people received were distributed over a 12-hour period.

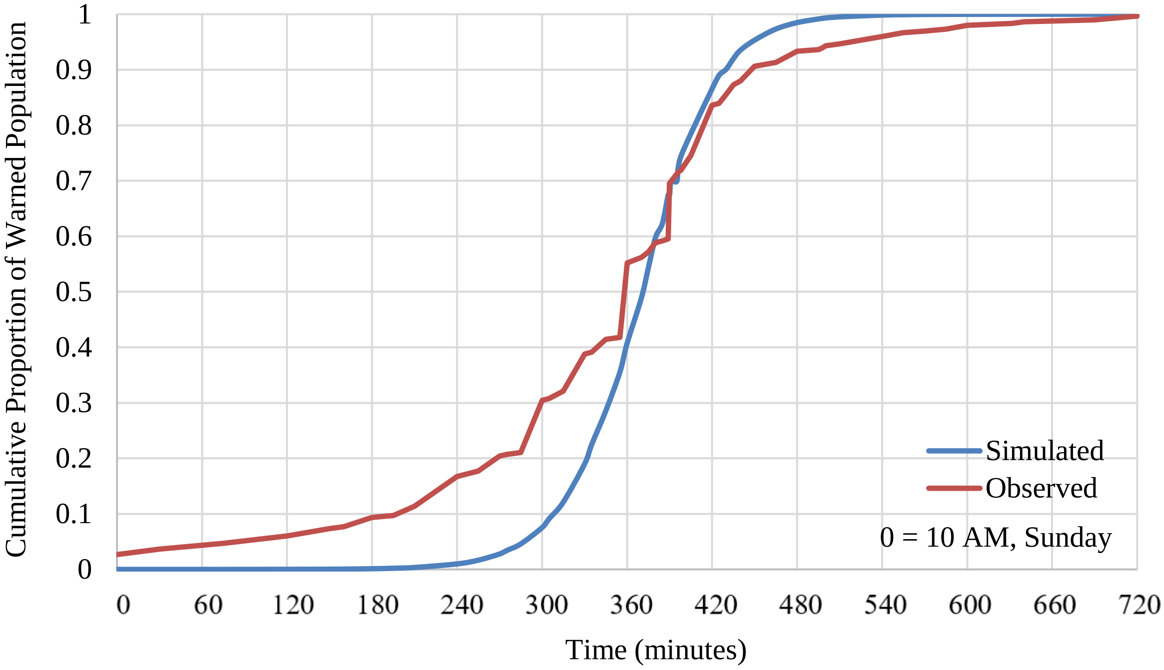


Figure 4-6. Comparison of simulated and observed first warning message diffusion for Population 1 (B_t = 6500; C_t = 0.11; Informal = 38.1%).

To reconcile this difference, the time scale of the model was adjusted to determine if the planning model coefficients could be better approximated. Figure 4-7 shows a comparison of a simulation where time on the horizontal axis is extended by a multiplier of three, reflecting a 12-hour period (720 minutes). The values of B_t and C_t are similar to the planning curve C daytime diffusion found in Figure 4-5. In addition, the percentage predicted to receive a warning from an informal source was 36%, closely approximating the portion in Population 1 receiving informal first warning messages (36.6%).

Another approach would be to eliminate the early warning time period in the simulation. For this approach, we simulated warning diffusion over the four-hour period beginning at 4:00 PM on Sunday. Figure 4-8 shows the results on the simulation when compared to the empirical data. The model cannot handle the vertical axis intercept of 0.55, but closely duplicates the results after the 30-minute time mark. If we compare it to Figure 4-5 planning curves, it most closely resembles a type B daytime dissemination system. The percentage predicted to receive a warning from an informal source was 39%.

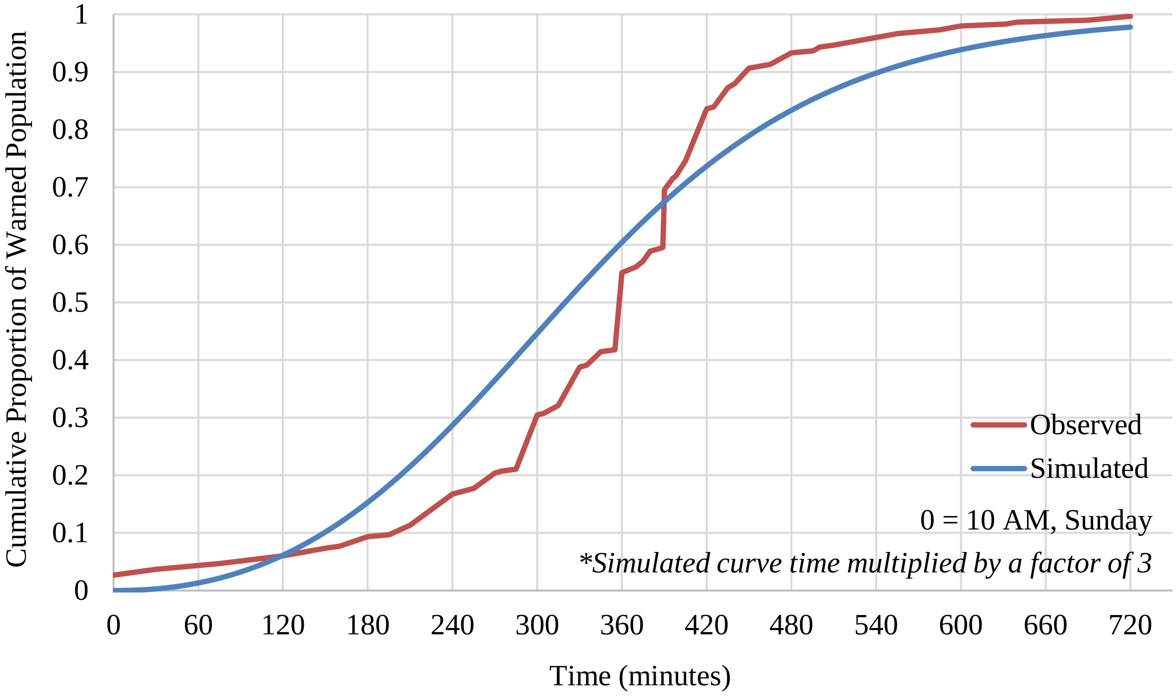


Figure 4-7. **Comparison of simulated and observed first warning message diffusion for Population 1 (B_t = 128; C_t = 0.023; Informal = 36% of total warning).**

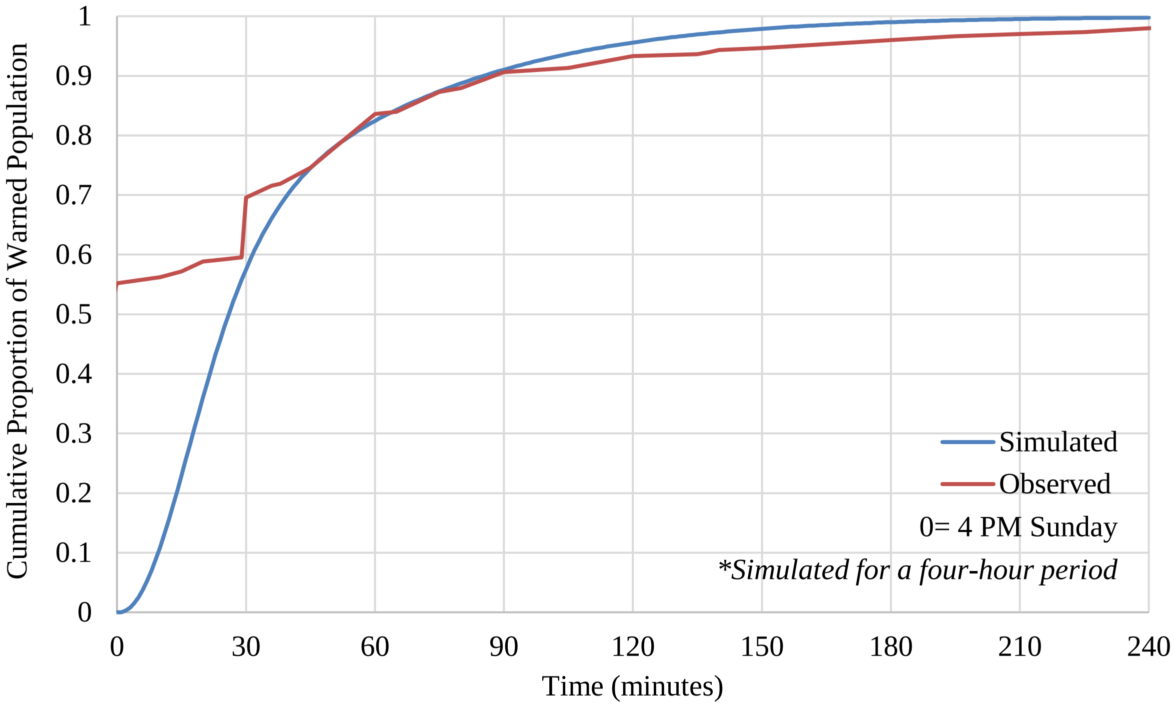


Figure 4-8. **Comparison of simulated and observed first warning message diffusion for Population 1 (Bt = 20; Ct = 0.025; Informal = 39%).**

4.7.4 Implications for Future Model Development

What we see in Figures 4-7 and 4-8 are simulated diffusion curves that are generally the same shapes with similar coefficients as our planning curves developed in earlier work. The simulated curves in both examples do not fully capture the initial slow warning receipt or the spike between 3:00 and 4:00 PM. The longer time frame simulation (Figure 4-7) cannot capture the rapid increase and then a diminished tail end of the curve. The four-hour simulation (Figure 4-8) can capture much of the rapid increase after 4:00 PM and the tail end of the distribution. This raises the issue about the appropriate simulation time frame for events such as the Oroville Dam event. On one hand, the analysis suggests that the class of warnings that occur over a day-long time frame for an uncertain threat should be treated somewhat differently than the warning curves for rapid onset events with a much more certain threat. In addition, events in which risk information is provided to the public for an extended period prior to the first official public warning might warrant different curves. Conversely, the four-hour simulation may capture enough variance to be appropriate for these types of events.

More sophisticated modeling of the warning diffusion process could be performed. For example, we know that people rarely respond to the first warning message by initiating a protective action; however, little has been done to model how multiple messages are diffused and received. Further modeling attempts could try to capture the dynamics of multiple message dissemination. This would likely require additional factors be measured in future research.

4.8 Recommendations for Future Data Collection and Analyses

4.8.1 Future Data Collection

Future research is needed on events with different characteristics and different types of locations. The event we studied provided important insight into how modern warning technologies work in an area characterized by small communities and a rural population in the context of a slowly evolving event. What we are lacking is data on an event in a much more urban environment where modern technologies may play a more major role in everyday life. And second, an event characterized by a sudden onset of a clear threat with no long pre-warning heightened risk setting should be examined. It is quite possible that the role of modern technology would be more predominant in events in a major urbanized location and that are of rapid onset with little pre-warning risk information circulation.

The official public warning activities for the Oroville Dam event occurred on a late Sunday afternoon and early evening, a time when most people were at home and awake. This doesn’t tell us about two other important situations: 1) how people receive warnings at night, and 2) how people receive warnings when they are less likely to be at home and family members are more likely to be separated. There may be a benefit to conducting future data collection on events that occur at night and events that occur on a weekday.

If a goal of future research is to construct diffusion curves for individual modern dissemination technologies, then that research will need to increase sample size beyond what would be needed to achieve a statistically representative sample. Oversampling would be needed to have a large enough number of people in the sample who received their first warning from the range of different diffusion technologies of interest. The larger sample size would dramatically increase survey costs. If such research were done in an urban area, the sample size would need to be at least twice what would otherwise be appropriate; however, if it were done in a predominantly rural area, it would need to be four to five times larger.

4.8.2 Future Data Analyses

Finally, the survey created a wealth of data on warning diffusion and the factors that may influence diffusion timing. This report provides a basic descriptive analysis of that data. We recommend that it be analyzed in more detail. First, empirical diffusion curves for the Oroville Dam event could be created that control for such as gender, education, income, race and ethnicity, age, and the other sociodemographic characteristics on which data was collected. We make this recommendation to account for the socioeconomic biases in the sample (see Chapter 3) and to discern if warning diffusion varies by warning receiver characteristics. Second, bi-variate hypothesis testing could be performed on any of the measured variables contained in the inventory of factors that predict differences in warning receipt time (see Table 4-1). Any hypothesis testing data analyses that are performed should consider controlling for socioeconomic status. Third, it is insufficient to full understanding of diffusion to cease analysis with descriptive analyses and bivariate hypothesis testing. Multi-variate causal modeling should be developed to better understand the factors that influence when people receive warnings.

5.0 FINDINGS FOR PROTECTIVE ACTION INITIATION (PAI) DELAY

5.1 Purpose

In this chapter, we examined protective action initiation (PAI) and PAI delay, in this event for an evacuation of both study populations. We define the concept of PAI, examine the factors that influence PAI delay, present the descriptive findings from the survey conducted on the event, construct PAI curves, and examine the relationship between those empirical curves and models of PAI. Recommendations for future data collection and further data analyses are then presented.

5.2 PAI Delay Defined

PAI delay is the period of time between receiving a first alert or warning and initiating the protective action. In this time period, most people take a range of actions to prepare to implement a protective action. The key protective action initiation question is "what delays people to begin taking a protective action after receipt of a first alert/warning or observation of environmental or social cues?" Several key activities that delay protective action initiation include milling or making sense out of the situation, reunification with family or intimates, and taking steps to prepare for the chosen protective action.

5.3 Factors that Influence Public PAI Delay

The factors that influence PAI delay are catalogued in Table 5-1. These factors are grouped into three categories of message, receiver, and context characteristics. Table 5-1 also proposes the relative importance of each factor as high, moderate, or low regarding its impact on PAI delay (see Sorensen and Mileti, 2014c for a complete discussion). Finally, the same table also lists the questions in the Public Survey Questionnaire for the Oroville Dam event (see Appendix 9) that measured some of these factors.

Table 5-1. Factors that influence PAI time.

FACTOR	IMPORTANCE	MEASURED BY *
Message Characteristics		
• Appropriate Content	High	Not Measured
• Style	High	Not Measured
• Message Length Adequacy	Moderate	Not Measured
• Personal	High	Q9, 10
• Delivery (Frequency)	High	Q19, 20, 21
• Protective Action Type	Moderate	Q7, 8
Receiver Characteristics		
• Status Attributes	Moderate	Q33, 34, 35, 36, 37, 38
• Role Characteristics	High	Q39
• Personal Preparedness/Planning	Low	Not Measured
• Pre-event Knowledge	Low	Not Measured
• Experience	Moderate	Not Measured
• Membership in a Socially Isolated Group	Moderate	Not Measured
Context Characteristics		
• Environmental Cues	High	Not Measured
• Social Cues	Moderate	Not Measured
• Location/Activity	Moderate	Q11, 12
• Day Versus Night	Low	Q8
• Time to Impact	High	Not Measured
• Impact Intensity	High	Q16, 17

See Appendix 9 for specific questions used.

5.4 Measurement

5.4.1 Timing of PAI

Protective action initiation and its timing was measured by using the following three questions:

Q25. Did you evacuate? **(CIRCLE ONE)**
1 = YES
2 = NO

Q27. What day did you begin your evacuation (by begin your evacuation we mean leave your location to go to a safe area)? **(CIRCLE ONE)**
1 = PRIOR TO FRIDAY, FEBRUARY 10
2 = FRIDAY, FEBRUARY 10
3 = SATURDAY, FEBRUARY 11
4 = SUNDAY, FEBRUARY 12
5 = MONDAY, FEBRUARY 13
6 = AFTER MONDAY, FEBRUARY 13

Q28. On that day, what time did you begin your evacuation (by begin your evacuation we mean leave your location to go to a safe area)? **(FILL IN BELOW WITH THE BEST ESTIMATE YOU CAN MAKE)**
HOUR _________ MINUTE _________ AM or PM _________

5.4.2 Factors Affecting PAI

Factors affecting PAI that were measured in the public survey are identified in Table 5-1 with reference to the questions in the survey associated with each factor. Not all factors associated with the timing of PAI were measured because they were not part of this study.

Measurements relating to message characteristics included if the first warning was received over a personal diffusion channel (Q9), if it was received from a personal source (Q10), the number of warning messages received (Q19), the number of different sources from whom messages were received (Q20), and the number of channels over which messages were received (Q21).

We also measured receiver characteristics, which included sex (Q33), ethnicity (Q34), age (Q35), level of education (Q36), income (Q37), occupation (Q38), and being in roles of responsibility for children, elderly persons, and pets (Q39).

Finally, we measured context characteristics, which included the activity in which people were engaged when they received their first evacuation message (Q11), where they were located when they received their first evacuation message (Q12), and if they received their first message during the day or night (Q8).

5.5 Descriptive Findings

We discuss a variety of topics related to evacuation in this section of the report. These topics include the information that people either received or sought in the time period after receiving their first evacuation message but prior to initiating evacuation, the actions people took prior to evacuating, how many people evacuated, why some other people did not evacuate, and more.

5.5.1 Channel of Additional Pre-Evacuation Messages

We asked people how many additional pre-evacuation messages they received after receiving their first message. Of the 363 people in Population 1 who answered this question, 42.7% (N=155) reported receiving no additional messages, and 57.3% (N=208) reported receiving additional messages prior to initiating their evacuation. Of the 349 people in Population 2 who answered this question, 30.7% (N=107) reported receiving no additional messages, and 69.3% (N=242) reported receiving additional messages prior to initiating their evacuation. Of those who reported receiving additional messages, Table 5-2 provides the percent of people in both Populations 1 and 2 who received them by channel type. What is significant is the relatively high number of people who left after receipt of the first warning message when compared to other historical warning event studies. However, these observations also provide clear evidence for the long-standing conclusion of historical research that a sizeable proportion of a population do not initiate a protective action after receipt of a first warning message.

It is also clear (see Table 5-2) that the communication channel over which most people received additional pre-evacuation messages was television (50.0% for Population 1, 55.8% for Population 2). This observation makes sense since historical research concludes that people seek additional information after receipt of a first warning message, and television is a readily available source for additional information.

The second most prominent way that people received additional pre-evacuation messages was via a text message over a mobile communication device such as a cell phone (25.5% in Population 1, 24.0% in Population 2), followed by face-to-face communication from another person, for example friend or family member (22.1% in Population 1, 19.0% in Population 22). Once again, these data are consistent with historical research, which concludes that receipt of a first warning message incites people to communicate with people they know.

The finding in Table 5-2 that was the most surprising was that few people reported receiving an additional pre-evacuation message over social media (Internet-social media such as Twitter or Facebook was 8.7% in Population 1 and 10.3% in Population 2). Some researchers and practitioners alike have touted social media as a powerful way to multiply the dissemination of official alerts/warnings in an at-risk human population. This was not observed in the Oroville Dam event.

Table 5-2. Channels by which additional pre-evacuation messages were received.

Addition Message Channel	Population 1 *% of Pop. (N)*	Population 2 *% of Pop. (N)*
Landline telephone with a recorded message	8.2% (17)	17.8% (43)
Landline telephone with a live person	10.1% (21)	7.0% (17)
Cell phone or other mobile communication device with a recorded message	14.4% (30)	16.5% (40)
Cell phone or other mobile communication device with a live person	17.8% (37)	18.6% (45)
Text message – On a mobile communication device such as a cell phone	25.5% (53)	24.0% (58)
Internet – An email	1.9% (4)	2.5% (6)
Internet – Social media such as Twitter or Facebook	8.7% (18)	10.3% (25)
Internet – Website	3.4% (7)	3.7% (9)
Face-to-face from an authority	6.7% (14)	5.4% (13)
Face-to-face from another person, for example friend or family member	22.1% (46)	19.0% (46)
An authority in the street with a loud speaker	8.2% (17)	3.7% (9)
Television	50.0% (104)	55.8% (135)
Radio	10.6% (22)	18.2% (44)
Tone alert National Weather Service Radio	3.8% (8)	6.6% (16)
Outdoor warning siren	2.4% (5)	1.2% (3)
Other	3.8% (8)	1.7% (4)
Total N (People who received additional messages)	**(208)**	**(242)**

5.5.2 Source of Additional Pre-Evacuation Messages

We also asked about the source of additional pre-evacuation messages. The most frequently cited source for additional messages received (see Table 5-3) was broadcasters over television radio, or the internet (54.3% in Population 1 and 54.1% in Population 2). This source category substantially led all other sources. Once again, this observation makes sense since people seek additional information after receipt of a first warning message, television is a readily available source for additional information, and the days-long broadcasting coverage of the event prior to the issuance of official evacuation warnings led people to seek out or expose themselves to communications from broadcasters.

The second most frequently reported source of additional messages received were members of people's social network (see Table 5-3). Family members or other relatives accounted for 31.7% in Population 1 and 32.2% in Population 2 of additional received messages. Additionally, neighbors or friends were a frequently reported source of additional messages (27.4% in Population 1, 26.9% in Population 2). Once again, these data are consistent with historical research, which concludes that receipt of a first warning message incites people to communicate with people they know.

It is interesting to note that the original official sources for the first warning message in the study populations (the Butte County Sheriff, the Sutter County Sheriff, and the Yuba County Sheriff) were also among the sources reported for subsequent messages received: 27.4% for the Butte County Sheriff in Population 1, and 7.4% and 14.0% for the Sutter and Yuba County Sheriffs, respectively, in Population 2. These findings likely reflect the frequency with which subsequent messages informed their audience about the original sources of the first warning source in the different involved counties. Yuba City Officials were also attributed (11.2%) as a source for additional warning messages. Yuba City is located in Sutter County and they also issued a warning for residents of that city even though those people had already been targeted with a first warning message by the Sutter County Sheriff.

Table 5-3. Sources from whom additional pre-evacuation messages were received.

Additional Message Source	Population 1 *% of Pop. (N)*	Population 2 *% of Pop. (N)*
Local police	13.5% (28)	7.4% (18)
Local fire department	6.3% (13)	2.1% (5)
Governor's office of emergency services	6.3% (13)	8.7% (21)
Cal fire	3.8% (8)	0.4% (1)
Butte County Sheriff	27.4% (57)	3.3% (8)
Sutter County Sheriff	1.0% (2)	7.4% (18)
Yuba County Sheriff	0.5% (1)	14.0% (34)
Yuba City Officials	0.0% (0)	11.2% (27)
California Department of Water Resources (DWR)	5.3% (11)	7.4% (18)
National Weather Service	7.2% (15)	7.0% (17)
Family member or other relative	31.7% (66)	32.2% (78)
Neighbor or friend	27.4% (57)	26.9% (65)
Employer	1.9% (4)	3.7% (9)
Co-Worker	4.3% (9)	4.1% (10)
TV, Radio, or Internet Broadcaster	54.3% (113)	54.1% (131)
Other	5.3% (11)	6.2% (15)
Total N (People who received additional messages)	**(208)**	**(242)**

5.5.3 Communication Channels to Seek Additional Information after Receipt of First Warning

Previous research on the post first warning receipt/pre-protective action initiation period provides repetitive evidence that people seek additional information by communicating with others prior to taking a protective action. Hence, we asked respondents in the study if they sought additional information by communicating with other people before taking a protective action, and over what channel that information was sought. Findings are presented in Table 5-4.

Most respondents reported that they had sought addition information by communicating with others after receiving their first warning message but prior to taking a protective action (90.7% in Population 1, 93.3% in Population 2). This confirms the long-standing conclusion of prior research that people mill about and interact with other people to collect additional information before starting a protective action.

Table 5-4 reveals that people were most likely to seek additional information by making calls to others using a cell phone (63.8% in Population 1, 68.0% in Population 2), and by face-to-face conversations with others (36.4% in Population 1, 40.4% in Population 2). These communication channels were followed in frequency of use by cell phone text messaging (33.5% in Population 1, 42.7% in Population 2); and land line phone calls (24.5% in Population 1, 23.6% in Population 2). All four of these communication channels involved reaching out to others in the form of one-on-one communication with another person for more information.

We were surprised that social media was reported as the least used communication channel to seek additional information (see Table 5-4). Respondents reported that the Internet-social media such as Twitter and Facebook communication channel was used by 16.2% of Population 1 respondents and by 14.3% of Population 2 respondents. However, we did not study how social media was used for purposes during the event.

These findings suggest that respondents were most likely to seek additional information using channels where they more-or-less personally interacted with others, and were least inclined to use social media. It may be that this result has more to do with the character of the populations included in this study since residents resided in communities where patterns of human interaction tend to be at the personal level. These findings may be different if the event had occurred in a large urban complex characterized by a more informal form of human interaction.

Table 5-4. Communication channels used to seek additional information following receipt of first warning message.

Information Seeking Channel	Population 1 *% of Pop. (N)*	Population 2 *% of Pop. (N)*
Face-to-face conversations	36.4% (137)	40.4% (144)
Landline phone call	24.5% (92)	23.6% (84)
Cell phone call	63.8% (240)	68.0% (242)
Cell phone text message	33.5% (126)	42.7% (152)
Internet—Social media such as Twitter or Facebook	16.2% (61)	14.3% (51)
Other	3.2% (12)	3.9% (14)
Did not seek additional information	9.3% (35)	6.7% (24)
Total N (People who received a warning)	**(376)**	**(356)**

5.5.4 Post First Warning Pre-Evacuation Activities

We know from past research that people who receive an evacuation message engage in a variety of activities prior to initiating a protective action like evacuation. Table 5-5 catalogues the pre-evacuation activities that people engaged in for both study populations for the Oroville Dam event. Most people engaged in one or more pre-evacuation activities (90.7% in Population 1, 91.3% in Population 2).

The most frequently reported pre-evacuation activities were focused on logistical and practical aspects of leaving home. People packed items to take with them on their evacuation (67.6% in Population 1, 75.0% in Population 2) and took steps to secure their would-be vacant home (47.3% in Population 1, 58.7% in Population 2). These finding are not surprising and are consistent with past research.

The second-most mentioned category of actions related to the people in their lives. People told others that they were going and where (41.2% in Population 1, 47.5% in Population 2); they reunited with their family members (38.0% in Population 1, 35.4% in Population 2); and they reunited with and/or attended to their pets (30.3% in Population 1, 34.0% in Population 2). These findings are also not surprising and consistent with past evacuation research. People prefer evacuating as a united family rather than as individuals. This includes pets for those who have them.

Finally, some respondents reported that they helped others get ready to evacuate (20.2% in Population 1, 19.7% in Population 2). Still others reported that they secured their businesses prior to leaving (2.9% in Population 1, 3.1% in Population 2).

An interesting point is that the number of people reporting actions prior to evacuation were somewhat similar for both study populations, but the time to estimated impact was quite different between the two populations. Population 2 would have had hours after receipt of their first evacuation message had a flood occurred, yet Population 1 had one hour or so prior to estimated impact had a flood occurred. Yet both populations took the time to prepare their home for evacuation, packed what they needed, told other where they were going, reunited with their family and pets, and helped others.

Table 5-5. What people did after receiving their first warning message prior to evacuating.

Pre-evacuation Activity	Population 1 *% of Pop. (N)*	Population 2 *% of Pop. (N)*
Reunite with family	38.0% (143)	35.4% (126)
Reunite or attend to pets	30.3% (114)	34.0% (121)
Secure home	47.3% (178)	58.7% (209)
Secure business	2.9% (11)	3.1% (11)
Pack items to take with them	67.6% (254)	75.0% (267)
Told others they were going/where they were going	41.2% (155)	47.5% (169)
Helped others get ready to evacuate	20.2% (76)	19.7% (70)
Other	9.3% (35)	5.6% (20)
Did not do anything before evacuating	9.3% (35)	8.7% (31)
Total N (People who received a warning)	**(376)**	**(356)**

5.5.5 *The Number of Households Who Evacuated*

We asked respondents if they took the recommended public protective action and evacuated (see Table 5-6). Of those who answered this question, 67.4% of the heads of households in Population 1 reported that they had evacuated, while 32.6% reported that they did not; and that 68.0% of the heads of households in Population 2 reported that they had evacuated while 32.0% reported that they did not. Media coverage suggested much higher compliance rates than were actually observed. The measured compliance rates, similar for both Populations 1 and 2, are consistent with a precautionary evacuation event which in this case was the potential breach of the emergency spillway that had not yet happened when the evacuation warning messages were issued.

Table 5-6. Evacuation behavior for entire population.

Evacuation Behavior	Population 1 *% of Pop. (N)*	Population 2 *% of Pop. (N)*
Evacuated	67.4% (287)	68.0% (263)
Did Not Evacuate	32.6% (139)	32.0% (124)
Total N (People who answered question 25)	**100.0% (426)**	**100.0% (387)**

Figure 5-1 shows the geographic distribution of evacuees and non-evacuees. Although those who did and did not evacuate were mostly evenly distributed through the study areas, there were some pockets in which smaller proportions of residents did not evacuate, likely due to geography. For example, in the far eastern portions of the City of Oroville and Palermo (Population 1), none of those individuals who took the survey evacuated. This is most likely because these households were not in the path of the dam failure threat due to higher elevation, even though they were in the area that received warnings. Another aspect of note is that all people surveyed from Plumas Lake evacuated, while only one of those from Wheatland did, despite both being distant from the dam (Population 2).

In general, the most difficult part of calculating compliance rates is defining the geographical area that forms the denominator for the calculation. We tried our best to define the populations we studied to contain addresses of people targeted by evacuation warning but excluding those at high elevations. The sampling method we used may have fallen short of excluding everyone at high elevations. It wasn't possible to enumerate a more refined population lists given the limited resources available for population definition. It is possible that the compliance rates listed in Table 5-6 above underestimate compliance rates for Population 1. It is likely that the compliance rates for Population 2 are more accurate than Population 1 because the terrain in Population 2 is less varied in elevation.

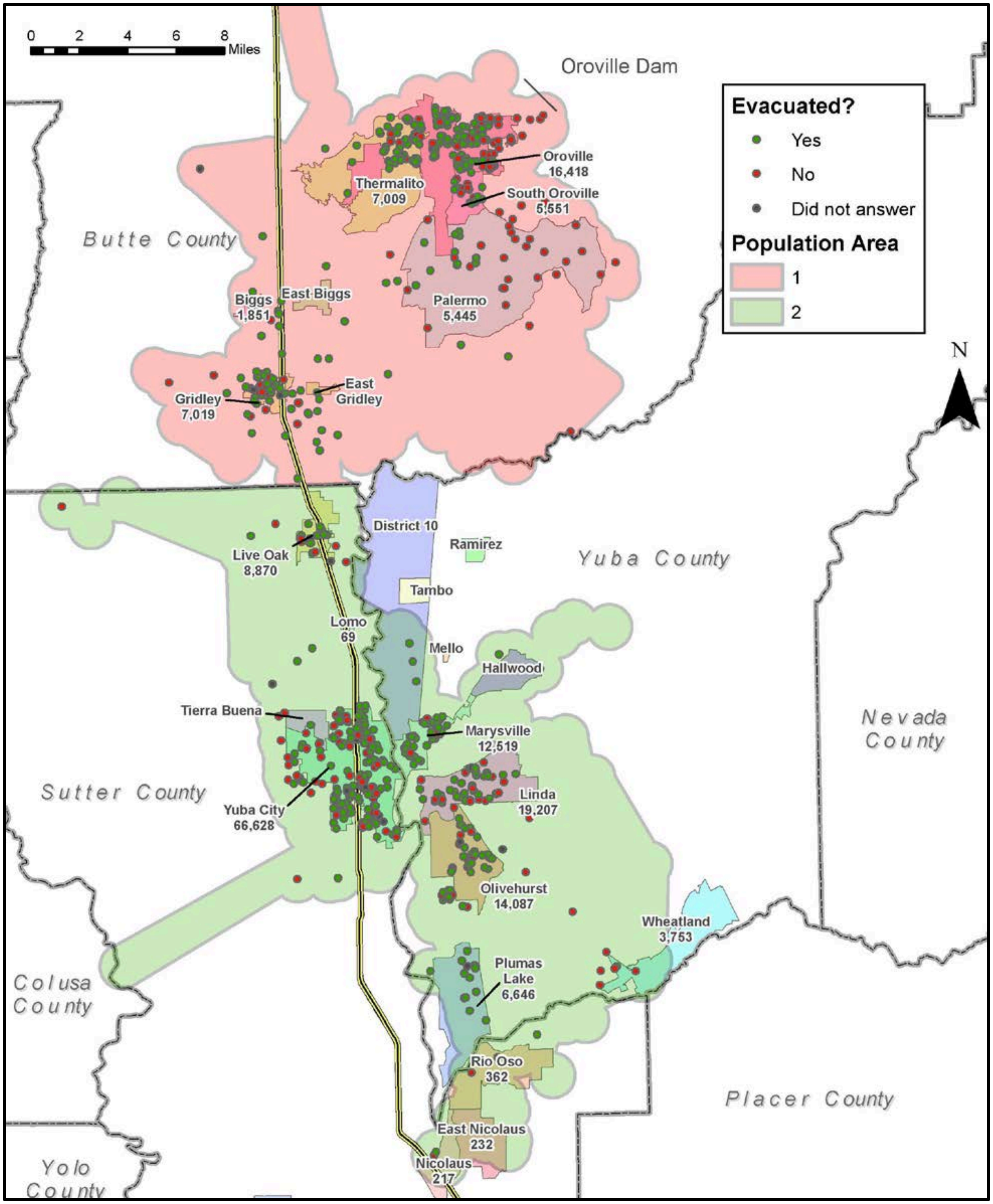


Figure 5-1. **Comparison of respondents in both populations who did and did not evacuate.**

There are several ways to refine our approach to estimating compliance rates. First, we could estimate if the location of each household in our sample was in or out of the flood risk area. Households in our sample that were out of the flood risk area could then be excluded when compliance rates are estimated. However, this approach would be problematic since the actual area at risk was not well-known or delineated at the time of the event. Second, we could exclude from consideration respondents who indicated they were not in an area at risk. A problem with this approach is that people may lack accurate perception of personal risk. Nevertheless, adjusted compliance rates were calculated when respondents who thought they were not at risk were eliminated from consideration (see Table 5-7). This was determined by excluding respondents who provided one of the following reasons for not evacuating in question 26 of the questionnaire (see Appendix 9): “Not in area told to evacuate” or; “Not in a low-lying area or an area that would flood.” These adjusted compliance rates show a higher percentage of people evacuating in both populations. In addition, it shows higher compliance in Population 1 than in Population 2 reflecting the higher level of risk and less time available in which to complete the protective action initiation.

Table 5-7. Evacuation behavior when eliminating respondents who reported they did not evacuate because they were not at risk.

Evacuation Behavior	Population 1 *% of Pop. (N)*	Population 2 *% of Pop. (N)*
Evacuated	83.4% (287)	74.9% (263)
Did Not Evacuate	16.6% (57)	25.1% (88)
Total N (People who thought they were at risk)	**100.0% (344)**	**100.0% (351)**

Furthermore, in many evacuation events a small portion of the population report evacuating without having received a warning message. This is generally attributed to several factors. These include that some people may have received a warning message but do not perceive it as such, people evacuate due to environmental cues such as rising waters without having received a warning message, or they evacuate due to social cues such as seeing others evacuating (Mileti and Sorensen, 1990). We examined the level of evacuation without receipt of a warning message in this event. In Population 1, 19 respondents (6.6% of evacuees) evacuated who reported that they did not receive a warning message. In Population 2, 18 respondents (6.8% of evacuees) evacuated who reported that they did not receive a warning message.

5.5.6 Why People Did Not Evacuate

People who reported that they did not evacuate were asked why they did not go. The reasons provided are listed in Table 5-8 for both study populations, and these fall into three categories.

First, people reported that they did not evacuate because they perceived that they were not at risk. Some respondents reported that they were not in a low-lying area or in an area that would flood (45.3% in Population 1, 20.0% in Population 2). Others reported that they thought they were not in an area told to evacuate (16.1% in Population 1, 10.0% in Population 2). Still others reported that they did not think there would be a flood (12.4% in Population 1, 25.8% in Population 2).

A second category of reasons given for non-compliance was that some people reported that they stayed behind to protect their property. This evacuation constraint was reported by 8.0% of respondents who did not evacuate in Population 1 and by 12.5% of respondents who did not evacuate in Population 2.

A third category of reasons provided for non-compliance dealt with evacuation constraints. Some people reported that they did not have the resources, for example, the money or a vehicle, to evacuate (3.6% in Population 1, 8.3% in Population 2). Some other people reported that they were physically unable to evacuate (3.6% in Population 1, 1.7% in Population 2).

A final possibility is that people did not evacuate because they did not receive an evacuation warning message. We explored this possibility in the absence of having asked a question about it in two ways. First, we examined open-ended responses to the question about reasons for not evacuating. No one in Population 1 and only one of the respondents in Population 2 indicated that they did not evacuate because they did not receive a warning. Second, we examined those respondents who reported not receiving a warning or evacuating, and did not provide a reason for not evacuating. Only two respondents in Population 1 and four respondents in Population 2 met these criteria. Based upon these analyses, we concluded that failure to receive a warning was not a significant reason for not evacuating.

Table 5-8. Reasons people reported for not evacuating.

Reason for not Evacuating	Population 1 *% of Pop. (N)*	Population 2 *% of Pop. (N)*
Not in area told to evacuate	16.1% (22)	10.0% (12)
Not in a low-lying area or an area that would flood	45.3% (62)	20.0% (24)
Stayed behind to protect property	8.0% (11)	12.5% (15)
Did not think there would be a flood	12.4% (17)	25.8% (31)
Stayed behind to do job	2.2% (3)	2.5% (3)
Did not have the resources, for example money or vehicle	3.6% (5)	8.3% (10)
Physically unable to evacuate	3.6% (5)	1.7% (2)
Other	8.8% (12)	19.2% (23)
Total N (People who did not evacuate)	**100.0% (137)**	**100.0% (120)**

5.5.7 Evacuation Destination

Study respondents who evacuated were asked about their evacuation destination (see Table 5-9). The overwhelming evacuation destination reported was to the home of a friend or relative (68.6% for Population 1, 68.9% for Population 2). The second most frequently reported destination was to a hotel or motel (9.5% for Population 1, 13.3% for Population 2). The third most frequently reported destination was to a public shelter (7.1% in Population 1, 4.5% in Population 2). These are the three most frequently used destination types in evacuations, and they typically follow the same order regarding frequency of use. Shelter use typically goes up as the age of the evacuating population increases and the personal affluence decreases.

Small percentages of use were reported for other evacuation destinations: churches (2.8% in Population 1, 0.4% in Population 2), campground or RV park (2.5% in Population 1, 2.3% in Population 2), and workplace (2.1% in Population 1, 1.5% in Population 2).

Table 5-9. Destination of people who evacuated.

Evacuation Destination	Population 1 *% of Pop. (N)*	Population 2 *% of Pop. (N)*
Public shelter	7.1% (20)	4.5% (12)
Friend or relative	68.6% (194)	68.9% (182)
Hotel or motel	9.5% (27)	13.3% (35)
Workplace	2.1% (6)	1.5% (4)
Church	2.8% (8)	0.4% (1)
Campground/RV park	2.5% (7)	2.3% (6)
Other	7.4% (21)	9.1% (24)
Total N (People who answered question 29)	**100.0% (283)**	**100.0% (264)**

5.5.8 Evacuation Time

The mean evacuation time for Population 1 was 2.17 hours. The range of evacuation times for Population 1 was 10 minutes to 30 hours with a median evacuation time of 1.5 hours. The mean evacuation time for Population 2 was 3.93 hours. The range of evacuation times for this population was 7 minutes to 50 hours with a median evacuation time of 3 hours.

5.6 PAI Curves for the Oroville Event

5.6.1 Curve Generation Method

The PAI curve for both Population 1 and 2 were generated based on people's responses to the question – "On that day, what time did you begin your evacuation (by begin your evacuation we mean leave your location to go to a safe area)?" This was coded as minutes past midnight. Rather than preparing a curve for the entire time period, we eliminated the people who evacuated before and after Sunday to focus on the day when most people evacuated (85.1% of the evacuated population in Population 1, 82.9% of the evacuated population in Population 2). Frequencies were calculated for each reported time of evacuation, and then a cumulative sum of the frequencies by time was calculated. These were expressed as both the percent of the total population (including those who did not evacuate or evacuated before or after February 12th) and as the percent of the population that evacuated on Sunday.

5.6.2 Whole Population PAI Curves (Populations 1 and 2)

Figure 5-2 shows the PAI time for Populations 1 and 2 on Sunday, February 12th. It does not include people who evacuated on other days before or after Sunday or people who did not specify time that they evacuated. The vertical axis shows the percent of the total sample population. The end-point of 48.5% thus tell us the percent of the evacuees that both left on

Sunday and knew the time that they evacuated. For Population 2, the endpoint of the Sunday evacuation in Sutter and Yuba county was 49.5%.

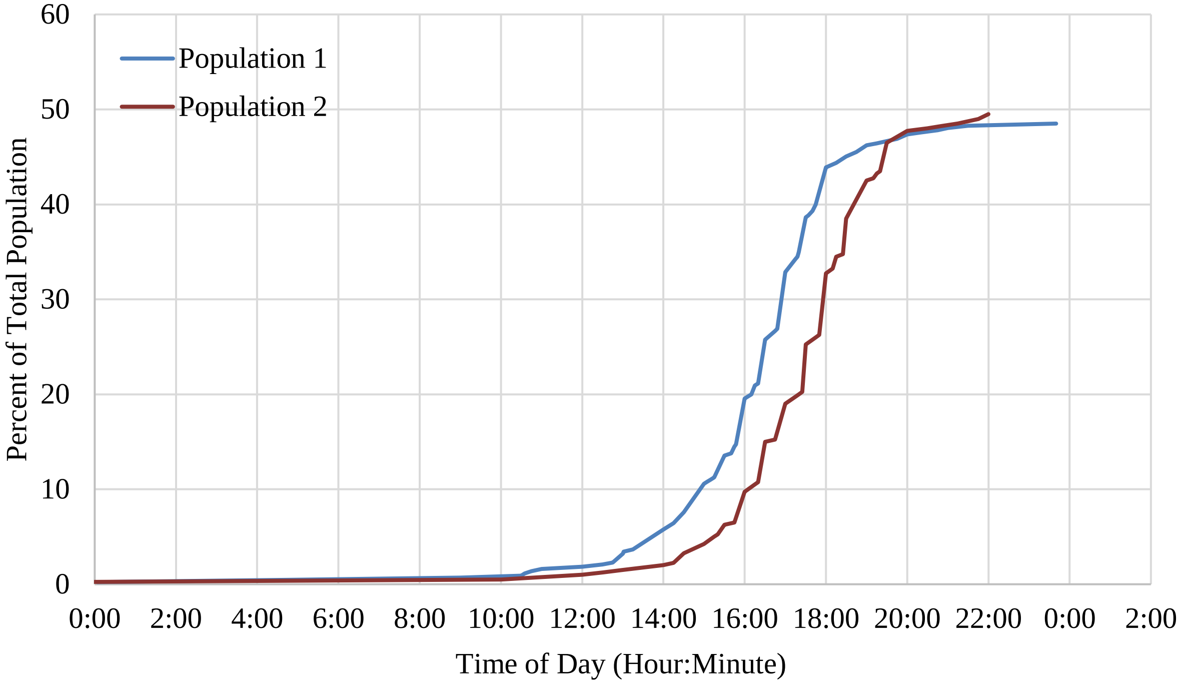


Figure 5-2. PAI curves for respondents who reported evacuating on Sunday, February 12 (Populations 1 and 2).

5.6.3 PAI Delay Curves

PAI delay is defined as the time between receiving the first warning and initiating the protective action (see Figure 1-1). Thus, it is a time interval and not a point in time. It was calculated for the subset of the population who received a warning and took an action on Sunday, February 12th. We limited the curve to Sunday to reduce the number of outliers depicted by the curves. This still captures over 90% of the evacuees in both populations. Mathematically, it is the difference between the time people reported to evacuate and the time they indicated that they received their first warning message. It can be less than zero when people evacuate before hearing a warning.

As shown in Figures 5-3 and 5-4, the general shape of the delay curves is similar for both populations. Although the figures show the same curve, the second depicts a shorter timeframe to illustrate the critical portions of the curve in more detail. As one would expect, the delay curve for Population 1 is steeper than for Population 2, reflecting the greater risk and the less time to respond before potential impact. It is significant to note that in Population 1, about 32% indicated that they initiated evacuation before receiving a first evacuation message from any source. The corresponding number in Population 2 is 25%. This is consistent with other protracted events where many people evacuate before receiving a warning based on their interpretation of the event and situational perception of risk. Furthermore, some people take precautionary actions before official actions for a variety of reasons including the desire to avoid road congestion if an evacuation is ordered or a preference to err on the side of caution.

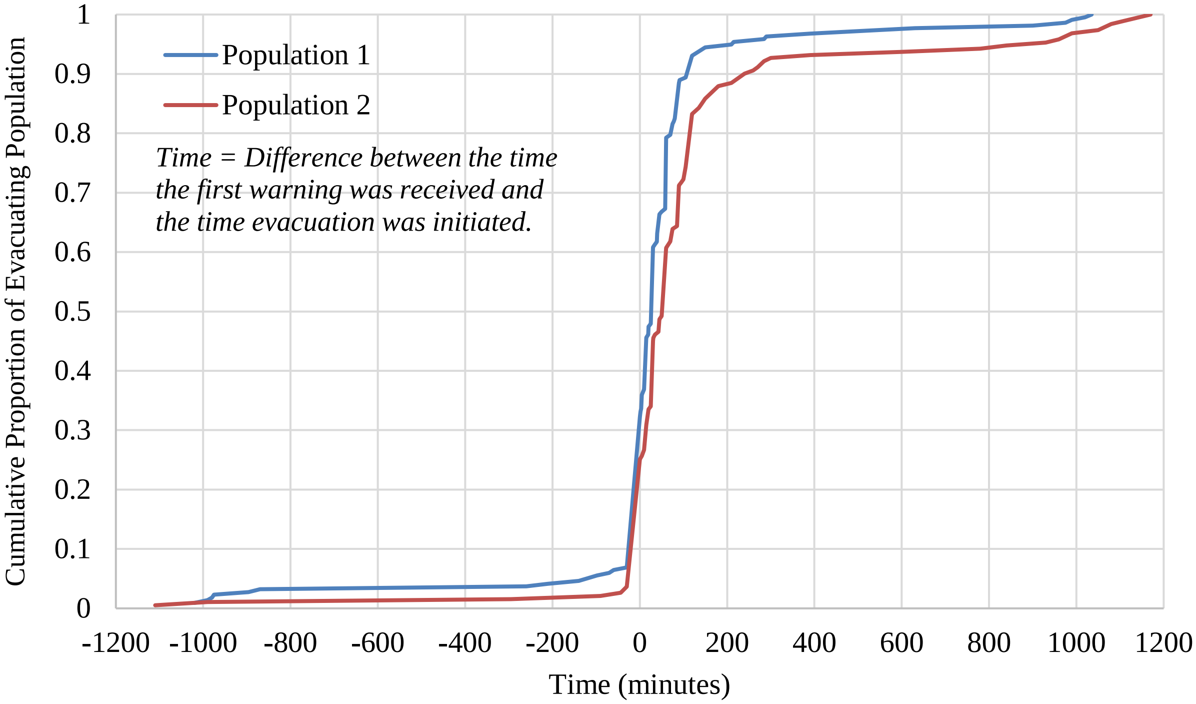


Figure 5-3. **PAI delay curves for respondents who reported evacuating on Sunday, February 12 (Populations 1 and 2).**

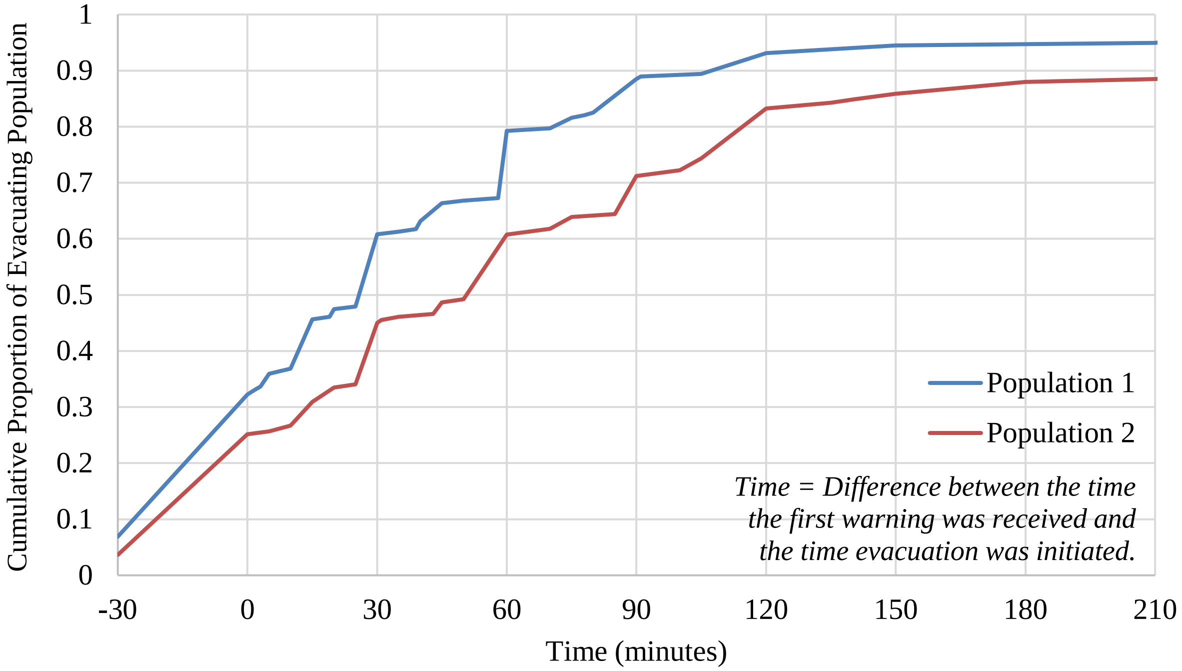


Figure 5-4. **PAI delay curves for respondents who reported evacuating on Sunday, February 12 for a 4-hour period (Populations 1 and 2).**

5.6.4 PAI By Channel Type for Populations 1 and 2

To gain a better insight into the essential question of whether receipt of first messages from certain warning dissemination channels lead to a timelier PAI, we looked at the PAI time based on the channel of message receipt. Due to the fact that many of the channels had insufficient numbers to generate curves, we used the following three categories of channels discussed in Chapter 4, Section 4.5.6: Modern, Traditional, and Informal.

Figure 5-5 shows the timing of PAI in Population 1 based on the channel category. People initiated PAI more rapidly when the first message came from an informal source (median time of 16:15). PAI time was slower for traditional sources (median of 16:47), with modern technologies falling in the middle (median of 16:27). Additional analysis is required to more fully explain this pattern of response.

Figure 5-6 shows the same curves for Population 2 where a somewhat different pattern emerges. Each category of warning channels has similar values up until 6:30 PM (18:30). The median times for the three technology types is close but show the same order as found for Population 1: 17:25 for informal, 17:30 for modern, and 17:50 for traditional. At that point, we see a divergence in the curves with surge of evacuations associated with receiving warnings from traditional channels followed by modern and then informal channels.

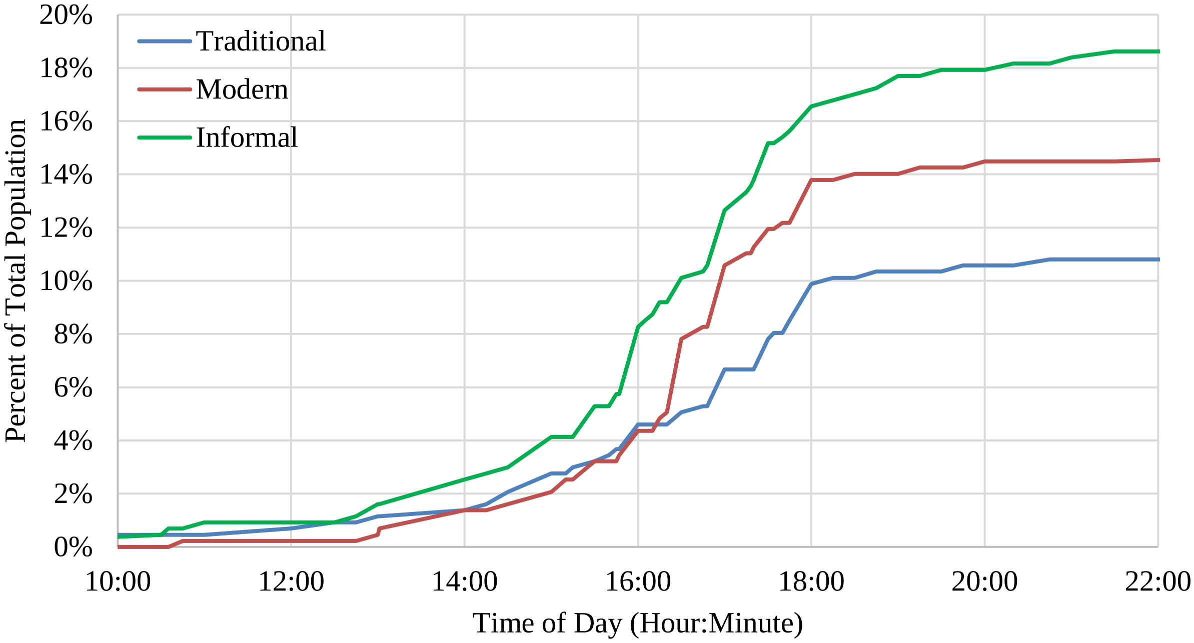


Figure 5-5. PAI curves for respondents who reported evacuating on Sunday, February 12 by warning channel type (Population 1).

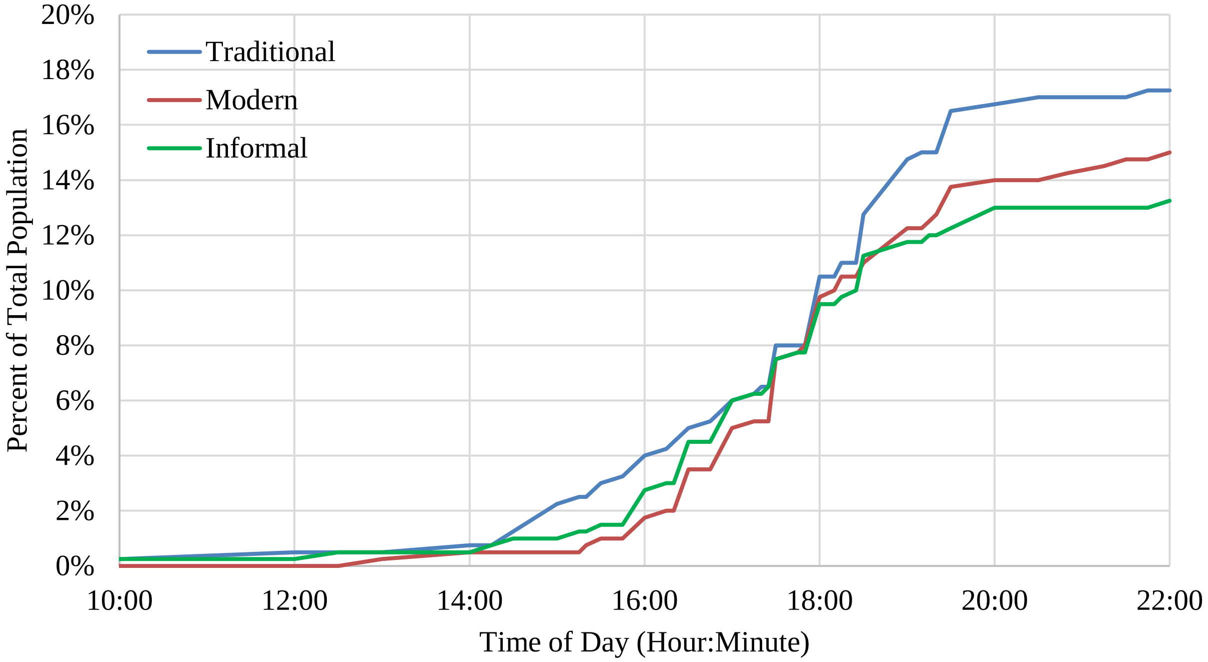


Figure 5-6. PAI curves for respondents who reported evacuating on Sunday, February 12 by warning channel type (Population 2).

5.7 Implications for Previously Recommended Curves

5.7.1 PAI Curve Modeling Simulation Method

In our previous work (Sorensen and Mileti, 2014c), we used a modified Rayleigh model approach similar to the one used by Lindell et al. (2002), Lindell and Perry (2004) and Lindell and Prater (2007). The model algorithm used is:

$$P_t = 1 - e[-(t^2)/ab^2)] \qquad (5)$$

Where:
P_t = the cumulative probability of taking action at time t
e = the natural logarithm
a = constant
b = constant

The constant b represents the median time for people to be mobilized, thus helping define the overall initiation period. As b gets larger, the total amount of time to complete the initiation of a protective action increases. The constant a describes the speed at which they mobilize. As a decreases from a value of 2.0, response accelerates. As a gets larger (greater than 2.0), responses decelerate. The algorithm calculates the probability of initiating protective action over time and the cumulative sum of the probabilities over time.

5.7.2 Historical Recommended PAI Curves

In our previous research, four planning curves were developed to illustrate the relationship between community planning and PAI time distributions (Sorensen and Mileti, 2014c). Model parameters (constants *a* and *b* in the equation presented earlier) for hypothesized top, middle and bottom curves considering what might occur represent the best and worst-case planning assumptions as well as two intermediate cases. Our planning basis PAI curves are presented in Figure 5-7.

Curve A (*a*=1, *b*=25) represents what we consider to be theoretically possible given current knowledge about motivating public protective action initiation for imminent and serious risks. We do not know of any community warning events that could be characterized by Curve A. We believe that Curve A could be achieved for initiating an evacuation in communities that have state of the art emergency warning and preparedness planning.

Curves B (*a*=1.5, *b*=45) and C (*a*=2, *b*=85) represent what we consider to be likely given a mix of factors present in a community that can both increase and decrease initiation time. These curves likely represent the bulk of communities in America. These curves would characterize a community with a less urgent threat than for Curve A. Curve B represents a community that has made some progress in improving its emergency warning and preparedness planning. Curve C would be more indicative of a community that has not.

Curve D (*a*=2.5, *b*=200) represents what we consider to be a community that has not planned nor invested in technologies for emergency warning. Response to any emergency is ad-hoc, not pre-planned, and thus, improvised. These communities likely do not believe they have a serious threat or that they will face any events that require rapid response.

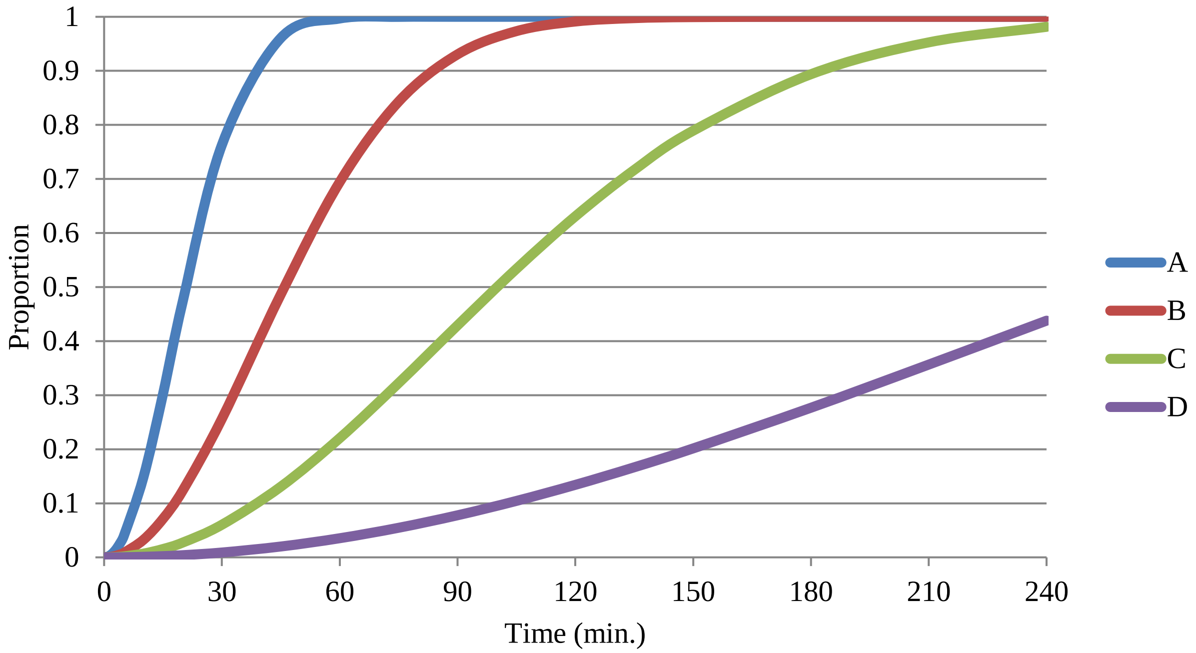


Figure 5-7. PAI planning curves.

5.7.3 Modeling the Oroville Empirical Curves

In this section, we take two approaches to modeling. First, we model PAI as a point in time. This is represented by the cumulative distribution of the time people indicated that they evacuated. In traditional evacuation time estimate modeling, this is referred to as a departure curve. Second, we model the PAI delay time as a segment of time, represented by the difference between when people indicated that they received the first warning message and when they evacuated (Sorensen, 1991). Researchers have also discussed modeling during this time phase in terms of a mobilization curve, defined as the time between the decision to evacuate and the evacuation departure (Sadri et al., 2013) or as the time to prepare to evacuate (Dixit et al., 2012). Lindell and Prater (2008) developed preparation time curves by asking people to estimate the length of time to complete key tasks: 1) prepare to leave from work; 2) travel from your place of work to your home; 3) gather all of the persons who would evacuate with you; 4) pack the items you would need while gone; 5) protect your property from storm damage (e.g., board up windows); and 6) shut off utilities, secure your home, and leave.

We only model the data for Population 1 in the Oroville Dam event because it is the study area closest to the source of risk and there is a distinct first official warning time (as opposed to Population 2 which had two different first warning times). The approach to modeling the data for Population 2 would be similar. We also only modeled PAI on the day of the warning when most of the evacuation departure occurred. We do not try to model very early or late evacuation.

5.7.4 Modeling PAI as Departure Time

The basic dilemma in modeling an event like this one, where much of the evacuation departures occurred before the official warning, is choosing an appropriate timeframe for the simulation of the PAI curves. If we attempt to model the entire 24-hour time period, we can only develop a curve that closely estimates the beginning, mid- and end-points and do not capture the shape of the overall curve. Therefore, the approach used is to model the empirical PAI curve starting sometime before the official warning (4:21 PM) and through the end of the day. In doing so, we used modeling parameters consistent with those used in the development of planning curves discussed above. We did simulations that began on Sunday at 2:00 PM (840 minutes past midnight) and at 3:00 PM (900 minutes past midnight). The results are shown in Figures 5-8 and 5-9. No attempts were made to optimize the parameterization of the curves, but rather to visually produce curves with close proximities to the empirical curve.

The simulations led to four important observations. First, the simulation fails to capture the initial rise of the empirical curves, thus they underestimate the number of people who left early. Second, the simulations accurately capture the steeper slope found in the middle portion of the empirical curve, capturing a critical period for estimating human behavior. Third, the simulated curves do reasonably well at capturing the tail end of the empirical curve, although slightly overestimating the response. Finally, the model parameters of a and b used in generating the curves are similar to those used in generating the planning curves in our previous work. The coefficient of $a = 2.0$ for both simulations and $b = 80$ or 120 in each respective simulation are similar to parameters used for planning curves B and C in the earlier work. Curves B ($a = 1.5$, $b = 45$) and C ($a = 2$, $b = 85$) represented what we considered to be likely curves given a mix of factors present in average communities that can both increase and decrease PAI.

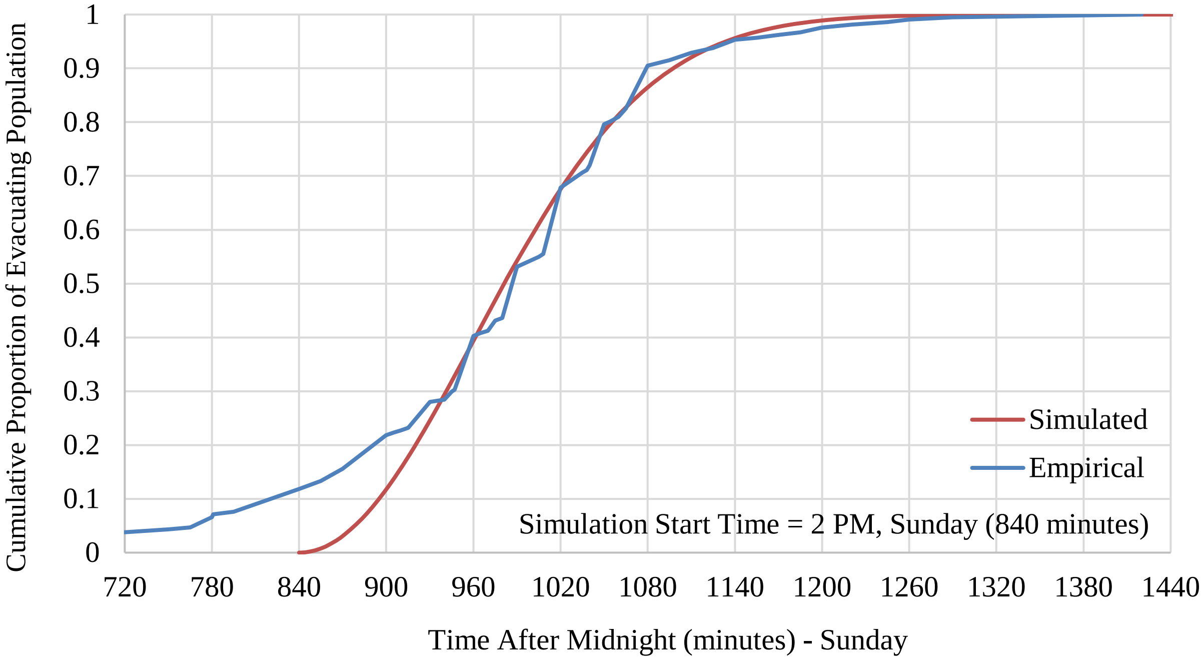


Figure 5-8. Comparison of simulated and observed PAI curves for Population 1 (*a* = 2.0; *b* = 120).

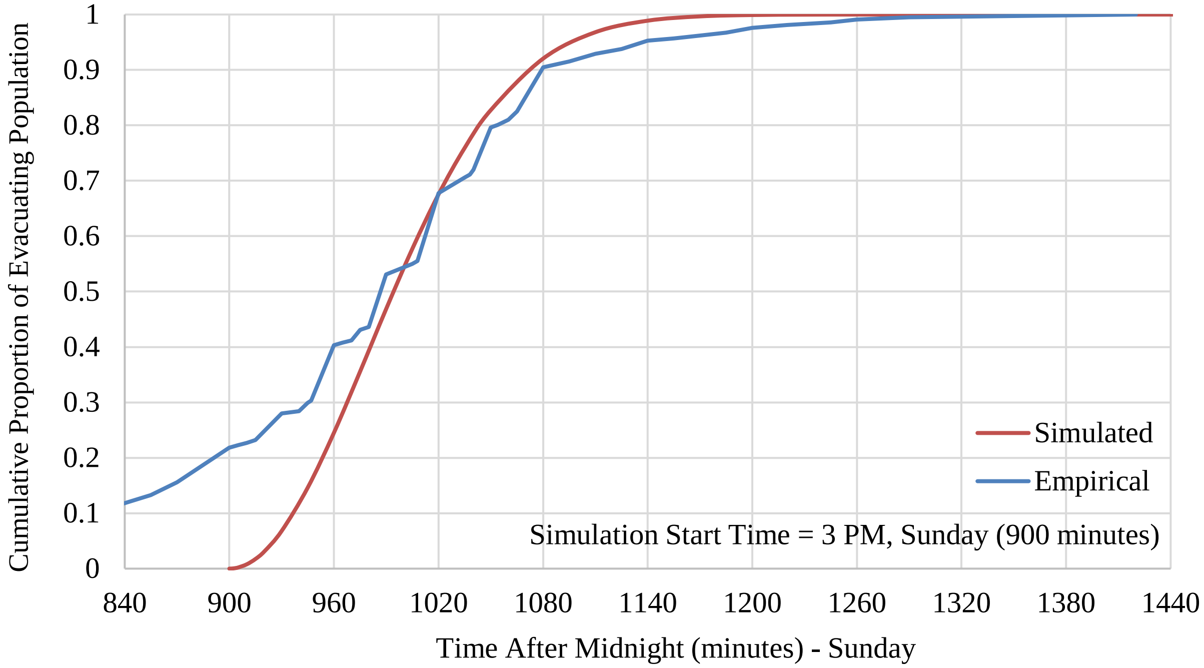


Figure 5-9. Comparison of simulated and observed PAI curves for Population 1 (*a* = 2.0; *b* = 80).

5.7.5 Modeling PAI Delay Time

In addition to modeling PAI as a departure curve, we model PAI delay expressed as the time period between warning and departure for each respondent. Figure 5-10 shows the results of simulation when compared to the empirical distribution. We began the simulation at negative 30 minutes to reflect respondents who received the warning after evacuating. The simulation underestimates short PAI delay and overestimates longer PAI delays, but does well at capturing the middle of the distribution. Changing the starting point of the simulation or optimizing the coefficient may produce a better fit. Once again, the significant finding is that the parameters used in the model resemble those used in developing the planning curves.

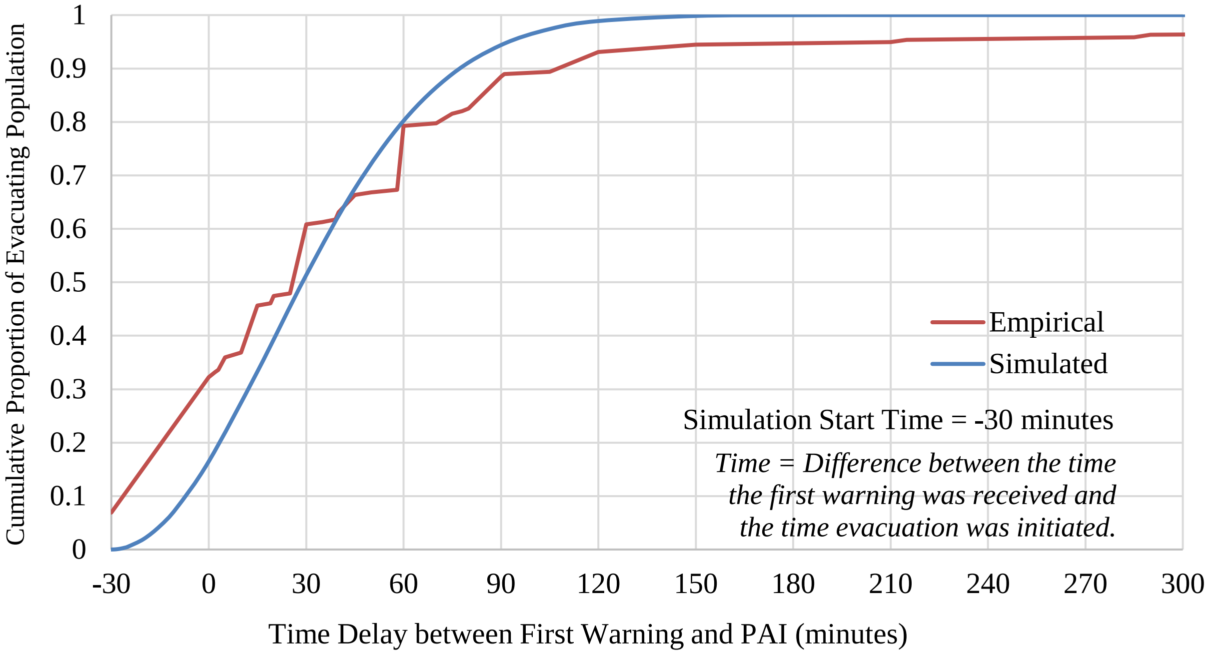


Figure 5-10. Comparison of simulated and observed PAI delay curves for Population 1 (*a* = 2.0; *b* = 50).

5.7.6 A Two-Phase Model of PAI

Since our simulation models were not strong in capturing either the early or late phase of the empirical PAI curve, we thought it might be useful to take a two-phase approach to the simulation and model early (defined as before the official warning) and post official warning PAI. While the precise method of integrating the two phases was not examined, Figure 5-11 illustrates the concept. In our two-phase model, the early phase simulation starts at minute 600 (10:00 AM) and ends at 960 (4:00 PM) (points displayed on the figure are from minute 600 to 950). The late evacuation simulation begins at minute 870 and ends at minute 1440 (points displayed on the graph are from minute 950 to 1400). Using this approach can more accurately simulate the empirical distribution. By doing sensitivity analysis of the appropriate simulation start time and optimizing parameters, this approach could accurately duplicate the empirical curve. Considerable additional work would be required to implement a two-phase simulation strategy.

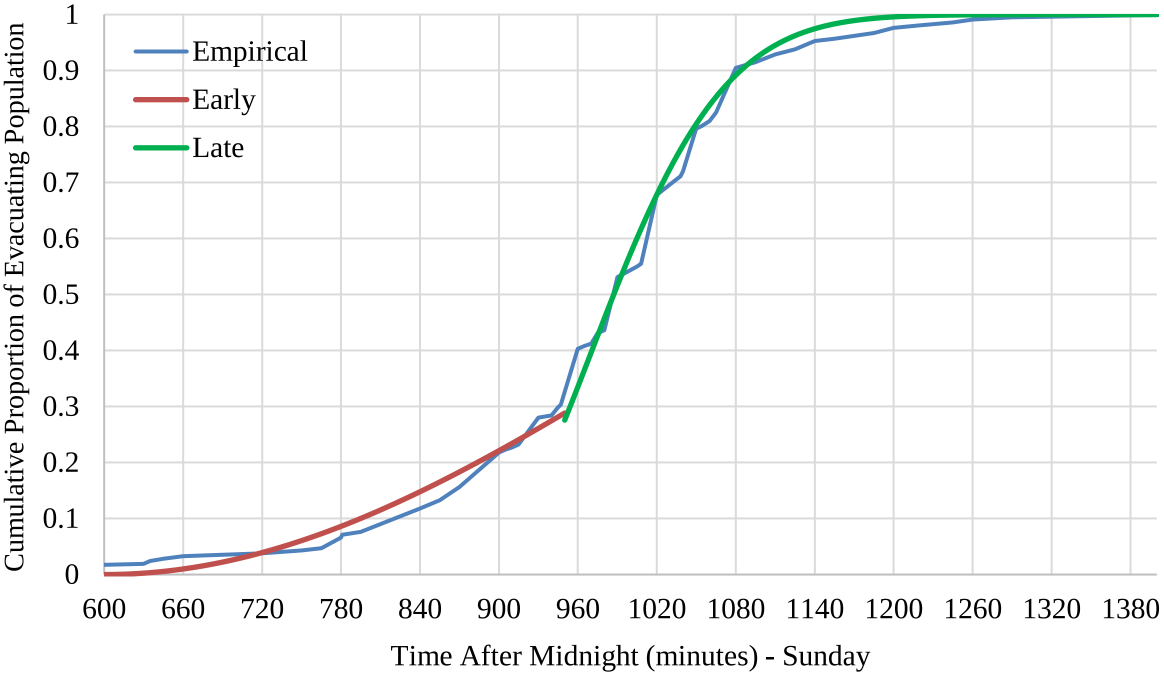


Figure 5-11. Example of a time phase simulation compared with observed PAI delay for Population 1 (Early: *a* = 1.0, *b* = 600; Late: *a* = 1.5, *b* = 115).

5.7.7 Implications for Future Model Development

Current curve development methodologies are based on a rapid evacuation scenario (a four-hour time frame with little or no early evacuation before the official warning). The Oroville Dam event evacuation occurred over a 12-hour or longer timeframe and the official warning came midway through that period. The current models are less adept at simulating PAI timing over that timeframe. Our earlier work did not consider events greater than four hours.

The models used do not accurately simulate the early evacuation given that 43.6% of the Sunday evacuees left before the official first warning. If we concentrate on the middle time phase of the evacuation, the simulations underestimate early PAI but more accurately capture the periods immediately before and after the official warning.

The two-phase modeling approach offers one potential means of capturing the 24-hour cycle of these types of events. This could be explored in more detail in subsequent work. Alternatively, a different modeling algorithm may be more appropriate for 12- to 24-hour events. PAI that occurs in events with longer time frames, such as in the case of multi-day hurricane evacuations, have empirical PAI curves that are modulated showing the impact of diurnal cycles and cannot be accurately represented by an equation with theoretical and empirical validity. Although some researchers have proposed the use of Probit models to capture PAI curves occurring over a multiday period (Dixit et al., 2012), those models cannot be adequately validated. A 24-hour period, however, should not display modulating characteristics and could possibly be approximated by multi-term equations.

5.8 Recommendations for Future Data Collection and Analyses

5.8.1 Future Data Collection

The Oroville Dam event provided lessons about PAI that can likely be generalized to future events occurring in rural settings and that are protracted over an extended period prior to issuing a protective action message. However, additional data is needed to fully understand PAI times in different events and settings. We have identified several areas where data collection would be beneficial to future PAI curve development and the understanding of the impact modern warning communication technologies have on PAI. We have prioritized them as follows:

High Priority Data Collection

Rapid Onset Event: A high priority type of event to be studied is one where there is no long or protracted buildup of the event prior to the distribution of a public protective action message. People in the communities downstream of Oroville Dam were exposed to considerable media coverage that gave conflicting risk information over a period of several days prior to the official warning. We are not confident that the findings from the current study would apply to a sudden onset flood event.

Urban Event: A high priority type of setting to be studied is one where the event occurs in a highly urbanized area. The people in this study largely lived in rural or small urban communities. The social character of people living in large urban areas differs in many ways from our study population that may likely impact PAI. For example, social interactions are more impersonal, technology plays a different role in communications, and the availability of resources may differ. Given these differences, we are not confident that the findings from the current study would apply in events that occur in highly urbanized areas. Furthermore, the increased prevalence of and access to modern technology in urban settings would provide the opportunity to better clarify the role modern technology warning channels play in shaping PAI.

Medium Priority Data Collection

Actual vs. Precautionary: In the Oroville Dam event, the evacuation warning was issued as a precautionary measure to protect people in the event that the emergency spillway failed. However, the spillway did not fail and no related flooding occurred. We know from historical events that people respond differently to precautionary warnings than to events where flooding has already begun. It would be desirable that a future event be studied in which initial media coverage of the event and issuance of the first public protective action warning occurred while flooding was happening. This would provide useful data about PAI compliance in a very different type of situation.

Non-evacuation Protective Actions: All of the PAI curves developed with empirical data have been from events where the protective action was evacuation (including the Oroville Dam event). A range of alternative protective actions exist for the hazard of flooding. It would desirable that a future event be studied in which a protective action other than evacuation is solely recommended, or one in which an alternative is recommended along with evacuation. For example, an event in which people are told to evacuate vertically or one in which a portion of the community is told to evacuate and another portion is told to take an alternative protective action and not evacuate. This will provide critical data for constructing non-evacuation PAI curves.

Low Priority Data Collection

Nighttime: In the Oroville Dam event, protective active decisions by members of the public were largely made in late afternoon or early evening when most people are awake. While it is not anticipated that PAI curves would be substantially different for a nighttime event when most people are initially asleep, the collection of such data could be used to either confirm or refute this assumption.

Multi-modal Evacuation: Current PAI curves including those developed for this study are based on the majority of people preparing to evacuate by private vehicle. Little PAI data exists for evacuations in which transportation modes other than private vehicle are highly utilized. For example, PAI time may be different in settings where people use public transportation to evacuate, evacuate on foot, or move to a safer building.

We are not suggesting that six new studies are needed to address all of these data needs. Ideally, additional future studies would address multiple needs.

5.8.2 Future Data Analyses

Almost all of the previous research conducted on protective action decision-making by the public has focused on understanding way people do or do not take a protective action. In comparison, little focus has been given to understanding PAI timing or delay. This research has collected extensive data on PAI time and has measured it in several different ways. Having this data provides a unique opportunity for analysis. We recommend that it be analyzed in more detail by developing empirical PAI curves for the Oroville Dam event that control for other criteria such as gender, education, income, race and ethnicity, age, and the other sociodemographic characteristics on which data was collected. We make this recommendation for two reasons: (1) to account for the socioeconomic biases in the sample, and (2) to discern if PAI time varies by warning responder characteristics.

Future data analyses should be conducted to determine the factors that best explain and predict variation in PAI times. First, hypothesis testing could be performed on any of the measured variables contained in the inventory of factors that predict differences in PAI (see Table 5-1). Any hypothesis testing data analyses that are performed should consider controlling for socioeconomic status. Second, it is insufficient to full understanding of PAI to cease analysis with descriptive analyses and bivariate hypothesis testing. Multi-variate causal modeling should be developed to better understand the factors that influence the time it takes for people to initiate protective action. Third, empirical PAI curves for the Oroville Dam event could be created that control for criteria such as socioeconomic status particularly given the identified sample biases (see Chapter 3). Finally, the data could be explored to see if they provide any insights to social vulnerability and its relationship to PAI time (see Morss et al, 2017).

6.0 CONCLUSIONS AND RECOMMENDATIONS

This section summarizes the major research findings from our study of the Oroville Dam event, discusses the implications for future research and data collection needs, suggests how the data from this study can be analyzed in more depth, and discusses future simulation modeling efforts.

6.1 Research Findings

6.1.1 Implications for Delay Curves

The data and analyses in both populations provide partial support for curve development and assignment that was developed in previous research. Our analysis provided strong support for modeling diffusion and PAI time following an official first warning over a short timeframe. However, we could not adequately model warning receipt or PAI before the official first warning was disseminated. The reporting of message receipt and PAI prior to official warnings in both populations was likely due to several factors such as pre-official warning risk information, recall error, normative bias, and anchoring (see Section 4.6.2). Consideration should be given to developing additional curves to represent longer duration events or events in which risk information is provided to the public for an extended period of time prior to the first official public warning.

6.1.2 The Impact of Distance

Our comparison of Population 1 in the jurisdiction adjacent to the dam (Butte County) to Population 2 in jurisdictions located further downstream (Sutter and Yuba Counties) was to assess if distance from the dam had an impact on outcomes regarding issuance, diffusion, and PAI. First, the issuance delay was shorter for Butte County than Sutter and Yuba Counties. Second, warning diffusion curves were similar in both populations. Finally, the PAI delay curve for Population 1 is steeper than for Population 2, reflecting that Population 1 was at greater risk and had less time to respond before potential impact.

6.1.3 Issuance Delay

By dividing this time period into two sub-periods (decision-making time and implementation time), we were able to further understand factors that contributed to issuance delay. We observed that issuance delay was shortest in Butte County because the warning initiator was physically with the risk detectors when they declared critical risk warranting a public evacuation first warning, thus shortening decision time. Nevertheless, the decision was delayed because the county warning decision-maker was never provided an inundation map prior to the event and did not have a warning plan threat matrix with planning scenarios and consequences. Other factors contributing to decision delays include time spent for key decision-makers to relocate to their EOC, having to write a first message (the lack of pre-scripted messages prepared as part of emergency planning), and the failure of warning dissemination technology (the lack of mutually exclusive and redundant technology as well as drills, testing, and exercises).

6.1.4 Diffusion

The findings of this study leave us to be apprehensive about generalizing what we learned about diffusion to other types of events. We are unable to answer significant questions about the relative roles of major diffusion technology classes (informal, modern, traditional) in different event types and locations, such as those that occur in less rural locations or sudden impact events with little forewarning. What we learned about diffusion in the Oroville Dam event may be confined to diffusion in slow onset events in rural communities, and we don't know if we can generalize to other event types. Given this caveat, what we learned in this study was that modern technologies did not perform as rapidly as has been speculated by some researchers and emergency managers. Furthermore, social media played a minor role in the receipt of both the first warning and subsequent warning messages. This again contradicts speculation by some researchers and emergency managers.

6.1.5 Protective Action Initiation (PAI)

Some people in both study populations initiated evacuation (the recommended protective action in the first warning messages) before the first official warning messages were disseminated. Although this type of early evacuation is found in almost all warning events, it is rarely found at this relatively high level. We speculate that was high in the Oroville Dam event due to the extensive media coverage that occurred for days prior to the official first warning, and the contradictory information about the safety of the dam presented to the public during that time without rumor control from emergency management agencies.

It is surprising that people did not initiate protective action more quickly after receipt of the first warning. The speed of PAI and the activities taken prior to evacuation was similar in both populations. The percentage of the populations complying with the recommended protective action were lower than expected, particularly in Butte County where risk was high and available response time was short. The observed compliance rates were nearly identical between the two populations. When controlling for perceived area of risk, compliance rates were higher in Butte County than the downstream counties.

6.1.6 Factors Limiting Generalizations

Generalization of the Oroville Dam event study conclusions are limited by several key factors inherent to the event. First, the findings are applicable to an area that is comprised of population in rural areas and small urban communities. It is likely that they would not apply in a major urban setting. Second, the conclusions apply to a slow onset event that unfolded over five days where extensive risk information was provided to the public prior to the first official public warning. We don't know if they would apply to a rapid onset event occurring over a shorter period of time. Third, study conclusions about the role and effectiveness of modern technology in the diffusion of first warning and the role it plays in shaping PAI time may not apply in an area that had a greater level of modern technology penetration. Finally, our conclusions are based on a dataset that under-represents people of low socioeconomic status. Subsequent partial-data analysis should be performed to determine if our conclusions apply to people in different social classes.

6.2 Future Research and Data Collection

6.2.1 Issuance

Issuance time data and the relevant community characteristics should by systematically collected for major flash flood events in general, and for dam incidents and levee failures in particular. This will greatly improve our understanding of issuance delay and allow more robust assumptions to be made and algorithms refined in models simulating the loss of life for flood events. The systematic study of issuance delay suggested above would not be a time consuming or expensive endeavor.

6.2.2 Survey Research on Diffusion and PAI

Future research is needed on events with different characteristics and in different types of locations. The event we studied provided important insight into how modern warning technologies work in an area characterized by small urban communities, in rural settings, and in the context of a slowly evolving event. To expand our knowledge about diffusion and PAI the following data collection efforts are recommended:

High Priority Data Collection

Rapid Onset Event: A high priority type of event to be studied is one where there is no long or protracted buildup of the event prior to the distribution of a public protective action message. People in the communities downstream of Oroville Dam were exposed to considerable media coverage that gave conflicting risk information over a period of several days prior to the first official warning. Issuance delay, warning diffusion time, and PAI times are all likely influenced by this event characteristic.

Urban Event: A high priority type of setting to be studied is one where the event occurs in a major urbanized area. The people in this study largely lived in rural or small urban communities. The social character of people living in large urban areas differs in many ways from our study population that may likely impact both warning diffusion and PAI. For example, social interactions are more impersonal, technology plays a different role in communications, and the availability of resources may differ. Furthermore, the increased prevalence of and access to modern technology in urban settings would provide the opportunity to better clarify the role modern technology warning channels play in shaping both warning diffusion and PAI.

Medium Priority Data Collection

Non-precautionary Event: In the Oroville Dam event, the evacuation warning was issued as a precautionary measure to protect people in case the emergency spillway failed. However, the spillway did not fail, and no related flooding occurred. We know from historical events that people respond differently to precautionary warnings than to events where flooding has already begun. It would be desirable that a future event be studied in which initial media coverage of the event and issuance of the first public protective action warning occurred while flooding was happening. This would provide useful data about issuance delay and PAI compliance in a very different type of situation.

Non-evacuation Protective Action Event: All of the PAI curves previously developed with empirical data have been from events where the protective action was evacuation (including the Oroville Dam event). A range of alternative protective actions exist for the hazard of flooding. It would be desirable that a future event be studied in which a protective action other than evacuation is solely recommended, or one in which an alternative is recommended along with evacuation. For example, an event in which people are told to evacuate vertically or one in which a portion of the community is told to evacuate and another portion is told to take an alternative protective action and not evacuate. This will provide critical data for constructing empirically-based non-evacuation PAI curves for the first time.

Low Priority Data Collection

Nighttime Event: In the Oroville Dam event, warning receipt and protective action decisions by members of the public were largely made in late afternoon or early evening when most people were awake. We know time of day will impact warning diffusion curves and it would be desirable to have nighttime curves for modern technologies. While it is not anticipated that PAI curves would be substantially different for a nighttime event when most people are initially asleep, the collection of such data could be used to either confirm or refute this assumption.

Multi-modal Evacuation Event: Current PAI curves including those developed in this study are based on the majority of people preparing to evacuate by private vehicle. Little PAI data exists for evacuations in which transportation modes other than private vehicles are highly utilized. For example, PAI time may be different in settings where people use public transportation to evacuate, evacuate on foot, or move to a safer building. The collection of data in a multi-model events could be used to develop PAI curves for this type of event.

We are not suggesting that six new studies are needed to address all of these data needs. Ideally, additional future studies would address multiple needs.

Given that this research underrepresented people with low socioeconomic status and racial and ethnic minorities, future survey research should use research designs that result in adequate representation of these sub-populations. For example, sampling strategies that overrepresent the poor, the uneducated, racial and ethnic minorities and more should be used. Moreover, the use of questionnaires in multiple languages (e.g. Spanish) would also assist in achieving these objectives.

6.3 Future Data Analysis

The analyses presented in this report regarding issuance, diffusion, and PAI were appropriate for a first level assessment, and hence were largely descriptive. Additional analyses could be performed on these same topics using more specialized approaches or on different data subsets. For example, analyses could be performed on subpopulations who evacuated, subpopulations who initiated a protective action only after receipt of the first official evacuation message, and more. These analyses could be used to possibly discover additional insights and reach more focused conclusions. Other specific recommendations about further analysis on diffusion and PAI follow.

6.3.1 Diffusion

The Oroville Dam event survey created a wealth of data on warning diffusion and the factors that may influence diffusion timing. We recommend that it be analyzed in more detail by developing empirical diffusion curves for the Oroville Dam event that control for other criteria such as gender, education, income, race and ethnicity, age, and the other sociodemographic characteristics on which data was collected. We make this recommendation for two reasons: (1) to account for the socioeconomic biases in the sample, and (2) to discern if warning diffusion varies by warning receiver characteristics. We also recommend testing bi-variate hypotheses on any of the measured variables contained in the inventory of factors (see Table 4-1) that might predict differences in warning receipt time. Finally, multi-variate modeling could be conducted to better understand the influence of multiple factors on when people receive warnings.

6.3.2 PAI

Almost all of the previous research conducted on protective action decision-making by the public has focused on understanding why people do or do not take a protective action. In comparison, little focus has been given to understanding PAI timing or delay. This research has collected extensive data on PAI time and has measured it in several different ways. Having this data provides a unique opportunity for analysis. We recommend that it be analyzed in more detail by developing empirical PAI curves for the Oroville Dam event that control for other criteria such as gender, education, income, race and ethnicity, age, and the other sociodemographic characteristics on which data was collected. We make this recommendation for two reasons: (1) to account for the socioeconomic biases in the sample, and (2) to discern if PAI time varies by warning responder characteristics. Future data analyses should be conducted to determine which factors best explain and predict variation in PAI times. This could be accomplished by testing bi-variate hypotheses on any of the measured variables contained in the inventory of factors (see Table 5-1) that might predict differences in PAI time. Finally, multi-variate modeling could be conducted to better understand the influence of multiple factors on when people initiate a protective action.

6.4 Future Modeling

6.4.1 Diffusion

We were able to produce simulated diffusion curves that are generally the same shape as the previously-developed planning curves by only modeling the middle portion of the Oroville Dam event empirical curves. Therefore, the simulated curves did not fully capture the initial slow warning receipt. The longer timeframe simulation did not capture the rapid increase and then a diminished tail end of the curve. This raises the issue about the appropriate simulation time frame for events such as the Oroville Dam event. On one hand, the analysis suggests that the class of warnings that occur over a day-long timeframe for an uncertain threat should be treated somewhat differently than the warning curves for rapid onset events with a much more certain threat. Conversely, the four-hour simulation may capture enough variance to be appropriate for these types of events. Future modeling efforts are needed to explore these issues in more detail.

6.4.2 PAI

Current PAI curve development methodologies are based on a rapid evacuation scenario (a four-hour time frame with little or no early evacuation before the first official warning is issued). In the Oroville Dam event, evacuation occurred over a 12-hour or longer timeframe and the official warning came midway through that period. The current models are less adept at simulating PAI timing over that timeframe. The models did not accurately simulate the early evacuation given that a large portion of the Sunday evacuees left before the official first warning. If we concentrate on the middle time phase of the evacuation, the simulations underestimate early PAI but more accurately capture the periods immediately before and after the official warning. The two-phase modeling approach explored in this study offers one potential means of capturing the 24-hour cycle of these types of events. This could be explored in more detail in subsequent work. Alternatively, a different modeling algorithm may be more appropriate for 12- to 24-hour events.

6.5 Conclusions

This study of the Oroville Dam event is the first comprehensive study of warning diffusion and protective action initiation conducted on an event where a large range of warning channels including modern warning technologies were utilized. To the best of our knowledge, it is the only scientific study done on public response to a protective action warning concerning a possible failure of a major dam in the United States. Furthermore, it is one of the few studies to have collected statistically representative data on two study populations, differentiated by their distance from the source of the threat. All three factors make this study both unique and valuable.

Overall the study confirmed many of the social science tenants concerning human behavior in response to emergency warnings. It provided new findings that challenge some of the current thinking about the role technology plays in contemporary emergency warning systems. It helped to identify strengths and weaknesses in our current efforts to model emergency warning dissemination and protective action initiation. Finally, it charts a course of action that can help answer many of the unanswered questions raised in the research findings.

7.0 REFERENCES

Dixit, V., Wilmot, C. and Wolshon, B. (2012). “Modeling risk attitudes in evacuation departure choices,” *Transportation Research Record: Journal of the Transportation Research Board*, No.2312, pp. 159-163.

Lindell, M.K. and Perry, R.W. (2004). *Communicating Environmental Risk in Multiethnic Communities*. Thousand Oaks, CA: Sage.

Lindell, M.K. and Prater, C.S. (2007). Critical behavioral assumptions in evacuation analysis for private vehicles: Examples from hurricane research and planning. *Journal of Urban Planning and Development*, *133*, 18-29.

Lindell, M.K. and Prater, C.S. (2008). *Behavioral Analysis: Texas Hurricane Evacuation Study*. College Station TX: Texas A and M University Hazard Reduction and Recovery Center.

Lindell, M.K., Prater, C.S., Perry, R.W. & Wu, J.Y. (2002). EMBLEM: *An Empirically-Based Large Scale Evacuation Time Estimate Model*. College Station TX: Texas A&M University Hazard Reduction & Recovery Center.

Mileti, D. and Sorensen, J. (1990). *Communication of Emergency Public Warnings: A Social Science Perspective and State-of-the-Art Assessment*. Oak Ridge, TN: Oak Ridge National Laboratory, U.S. Department of Energy.

Morss, R.E., Demuth, J.L., Lazrus, H., Palen, L., Barton, C.M., Davis, C.A., Snyder, C., Wilhelmi, O.V., Anderson, K.M., Ahijevych, D.A., Anderson, J., Bica, M., Fossell, K.R., Henderson, J., Kogan, M., Stowe, K., & Watts, J. (2017). “Hazardous weather prediction & communication in the modern information environment,” *Bulletin of the American Meteorological Society*, Vol. 98, pp. 2653-2674.

Rogers, G. and Sorensen, J. (1988). "Diffusion of Emergency Warnings," *Environmental Professional* Vol. 10, pp. 281-294.

Sadri, A. M., Ukkusuri, S. V. and Murray-Tuite, P. (2013). “A random parameter ordered probit model to understand the mobilization time during hurricane evacuation,” *Transportation Research Part C*, Vol.32, pp. 21-30.

Sorensen J. H. (1991). “When shall we leave? Factors affecting the timing of evacuation departures,” *Int. Journal of Mass Emergencies and Disasters*, Vol.9, pp. 153-165.

Sorensen, J.H. and Mileti, D.M. (2014a). *First Alert and/or Warning Issuance Delay Time Estimation for Dam Breaches, Controlled Dam Releases, and Levee Breaches and Overtopping*. Davis CA: USACE Institute for Water Resources Risk Management Center.

Sorensen, J.H. and Mileti, D.M. (2014b). *First Alert or Diffusion Time Estimation for Dam Breaches, Controlled Dam Releases, and Levee Breaches or Overtopping*. Davis CA: USACE Institute for Water Resources Risk Management Center.

Sorensen, J.H. and Mileti, D.M. (2014c). *Protective Action Initiation Time Estimation for Dam Breaches, Controlled Dam Releases, and Levee Breaches or Overtopping*. Davis CA: USACE Institute for Water Resources Risk Management Center.

Urbanik, T. (2000). Evacuation time estimates for nuclear power plants. *Journal of Hazardous Materials*, 75, 165–180.