Exploring and Bridging Group Divides in Climate Communications

Submitted in partial fulfillment of the requirements for

the degree of

Doctor of Philosophy

in

Engineering and Public Policy

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May 2017

Acknowledgements

First, I would like to thank the members of my committee for their guidance and support: Gabrielle Wong-Parodi, my advisor and committee chair, for pushing me onwards and for her amazing patience and understanding; Baruch Fischhoff, for his kind words and help in crafting an improved story; Mitch Small for his sense of calm, and Iris Grossmann for her practical advice and enthusiasm for my work.

Thanks to my friends and colleagues from EPP. Getting to know you all and share this experience with you has been the highlight of my time here and I wish the best for all of you, always. An enormous thank you to my family (all of them) for their continued love and support through all my journeys, especially this one.

Additionally, I would like to thank the EPP administrative staff for their hard work keeping us students all on track. Many thanks also to our research partners in FuturAgua and at One Montana for their support of my fieldwork and for all the fun and inspiring conversations. And, finally, a very special thanks to all the interview and survey participants in Guanacaste and Montana who were willing to share their time and their stories with me.

Funding

During my time here at EPP I was supported by several sources of funding. I was originally funded through FuturAgua, a Belmont Forum-G8 Initiative Collaborative Research project. Support for Carnegie Mellon's participation in FuturAgua was provided by the US National Science Foundation (ICER1342941-NSF). Additionally, my work was funded through a Federal Alliance for Safe Homes (FLASH) Scholarship, the Skoll Foundation, a Carnegie Mellon University Graduate Student Assembly/Provost Office Graduate Small project Help (GuSH) research grant, and the Department of Engineering and Public Policy (Thank you, Doug!).

Abstract

At the same time that additional coordination and cooperation between involved stakeholder groups is required more than ever to respond to changing environmental and socio-economic conditions, there has been an increasing trend of polarization across several important social divides (scientists/local actors, urban/rural, and political partisanship). Boundary organizations and boundary chains have been promoted as ways to help mitigate the problematic effects these divisions have on the successful communication of climate adaptation information in the water management sector.

In this dissertation, I present three studies that were conducted in two regions to further explore stakeholder groups and the boundary chains that connect them. Both areas (Guanacaste, Costa Rica and Montana, USA) are historically agricultural regions experiencing ongoing environmental and socio-economic shifts. A mental models approach involving the use of interviews and surveys was used in each study area.

The first two studies were conducted in Guanacaste and focused on comparing stakeholder group perceptions of their water system and hydro-climate information and on the differences in trust in forecast sources and its impact on forecast use. The results of these studies suggest that there is a distinction between the perceptions of larger stakeholder groups (e.g. government agencies or large farmers) and smaller groups (e.g. local water committees), and that this division suggests a need for boundary-type translation work.

The third study was conducted in Montana with a focus on what communication strategies are used by, and what prompts engagement with, a boundary chain connecting rural agriculturalists to urban scientists. The results show that members of the network generally agree that for successful communication it is important both to not engage in ways viewed as attacks on agriculture and to make attempts to understand and respect local agricultural contexts. While there is some tension in the network, overall “buy-in” to the goal of bridging divides appears to be a common reason for engagement. In addition, organizations engage with the boundary chain for both the opportunity to connect to others and because of the need for translation between the concerns and logistics of different groups.

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I. INTRODUCTION

We currently live in times of increasingly complex environmental, economic, social, and political change. Successful adaptation to such changes requires us to work across disciplines, groups, and temporal and spatial scales, now, perhaps, more than ever. Problematically, we also live in times of growing polarization in the media, politics, and potentially in the public realm. This polarization exacerbates the naturally sometimes steep barriers to successful science communication and coordination between important stakeholder groups, especially in already complex socio-ecological domains, such as the management and adaptation of water resource systems under changing climate conditions. This dissertation presents three studies exploring the divisions between stakeholder groups and examining the organizations and strategies that are attempting to bridge those divisions. It is hoped that insights from this work may be helpful in enabling more successful communication across groups, which in turn, may lead to more informed decision making and coordination related to climate adaptation of water resource systems.

1.1 Changing conditions require different decision making strategies

Increasingly, changes in climatic patterns, socio-economic pressures, and other large-scale drivers of water systems have created contexts in which older water management practices and decision-making strategies are not adequate to meet the demand for freshwater in multiple regions. Successful freshwater resources management under changing climate patterns and socio-economic pressures is a complex task that involves diverse stakeholder groups and decision making at multiple spatial and temporal levels. Traditional understanding of the system and strategies that were successful under more predictable conditions may not be so under such changing conditions. Therefore better use of new climate and adaptation information by the involved stakeholder groups has become more important (Kirchhoff et al. 2013).

Over the last several decades, there has been a recognition of the need to involve additional stakeholder groups, some of whom increasingly may be skeptical of the underlying science, in the water management process and to assist efforts to communicate climate and adaptation information between them in order to ensure informed decision making is taking place in different parts of the connected system (Pahl-Wostl et al. 2007, 2008). This inclusion of different groups and their goals makes up a large part of what is termed integrated water resources management (IWRM). Parallel to the interest in IWRM has been a push for adaptive management in the water sector. Adaptive management is intended to learn from previous outcomes and be flexible enough to act on that learning, in coping with increasing uncertainties in the water system (Pahl-Wostl et al. 2007, Engle et al. 2011). Like IWRM effective adaptive management also requires increased communication and coordination amongst the different groups involved in the system.

1.2 Societal divisions exacerbate barriers to science communication

A large body of literature exists concentrating on the barriers to the use of modern climate and adaptation information by water managers in many different sectors and to the successful communication and coordinate between groups. Many of these barriers are due to and exacerbated by increasing societal divisions. Three main divisions of importance emerge in studies of water and climate adaptation communication: scientists vs. local actors, rural vs. urban groups, and political divisions. Each division has grown wider and threatens to grow wider.

Scientists/Local Actors - Because climate science is both complex and uncertain, successful communication of it is challenging. Therefore misunderstanding between those that produce science research and local actors (e.g. agriculturalists, municipal systems operators, and hydroelectric project managers) who use that information may grow. This is problematic because research has shown that positive interaction between scientists and local actors is an important component in creating useful and usable climate and water management tools and strategies. Cash et al. (2003) suggested that in order for scientific environmental communication to be successful, it must be credible (technically accurate), salient (relevant to users' needs) and legitimate (respectful of values and fairly created). Lemos et al. (2012) expand on this framework in their concepts of "fit" (information that is credible, salient, useful, and timely), "interplay" (the information that can be incorporated into the current management environment), and "interaction" (the process is legitimate, two-way, and iterative). Increasing distance between scientists and local actors most obviously interferes with the "interaction" aspects of successful communication, but also affects "fit" and "interplay," as producers of science tools have less of an idea about the contexts in which potential users are operating.

Urban/Rural – In many areas, the rural/urban population balance is changing and with that change comes opportunities for cooperation and the potential for mistrust. Additional stress on water resources due to environmental and socio-economic change in some areas has forced rural and urban groups to interact with each other more so than previously (Hiner 2015). New interactions can lead to additional recognition of the existing and growing physical and economic connections between rural and urban areas that enables more integrated regional management. On the other hand, new interactions can also result in accusations and disputes over disproportionate use and/or control of water resources, leading to a breakdown of integrated management.

Political Identity - In the United States and elsewhere, there appears to be growing partisan polarization in both the media and political classes (Prior 2013, Fiorina and Abrams 2008), with the potential for that polarization to continuously spill into a polarization of public and other stakeholder groups (Druckman et al. 2013). This shuts down lines of communication and exacerbates both the distance between groups and many of the other barriers mentioned in the climate information exchange literature (Kirchhoff et al. 2013, Lemos et al. 2012). As polarization grows, political identity appears to bleed even more into environmental and climate debates (Bliuc et al. 2015, Dunlap et al. 2016).

The confluence of these divides (sometimes but not always appearing as a split between Urban/Left/Scientists and Rural/Right/Local Actors), erodes trust, silences lines of communication, and can lead to additional misinterpretation. The trends are that as there are more complex environmental science problems, the Scientist/Layperson gap grows; as there are more population and economic shifts, the Urban/Rural interface and level of interaction changes and misunderstandings potentially grow; and as there have been several decades of increasing political vitriol and group identification, there is the risk of everything being separated into opposing political camps (Zhou 2016, Dunlap et al. 2016). As such divisions grow, group interactions may become strained at just the time when changing climate and economic conditions require additional coordination between groups on opposite sides of the divides. It is therefore important to explore how to strengthen the connections between groups to withstand increased polarization.

1.3 Improving science communication and using boundary organizations

There have been efforts to both describe the social divides and to identify strategies and structures that help bridge them. The goals in integrated and adaptive water management are coordination among stakeholders and iterative informed decision making. A first step toward meeting these goals requires paying attention to the basics of successful science communication: the need to be aware of the potential user's perceptions, choices and decision environments, and the need to develop trust between the producers and users of such information (or between two groups that have potentially helpful information for each other) (Fischhoff 2013). For example, it is difficult if not impossible to meet Lemos et al.'s "fit, interplay, interaction" criteria if scientific researchers know nothing about the local context to which their information is targeted. Similarly, successfully reaching across either the urban/rural or the conservative/progressive divides requires an awareness by each side for the experiences, perceptions, resources, and constraints of the other.

Recently there has been additional focus and observation by researchers of the importance of not only knowing how different groups perceive and act and therefore designing communications that work well for those groups, but also on increasing the positive interaction of groups as a way of decreasing the social distance between them.

Boundary organizations have been promoted as ways to accomplish both tasks: developing communications appropriate to the needs of diverse stakeholder group and increasing trust between them (Kirchhoff et al. 2015). Boundary organizations have traditionally been thought of as connecting scientific analysis and decision makers as well as across institutional scales (Guston 1999, Cash and Moser 2000). Cash and colleagues summarize boundary organizations as promoting, "(1) accountability to both sides of the boundary; (2) the use of “boundary objects” such as maps, reports, and forecasts that are co-produced by actors on different sides of a boundary; (3) participation across the boundary; (4) convening; (5) translation; (6) coordination and complementary expertise; and (7) mediation” (Cash et al. 2006). Organizations such as the Office of Technology Assessment, which once provided science-related policy analysis to congressional committees, and agricultural extension agencies which continue to connect researchers with local agriculturalists both have played or do play boundary organization-type roles in their respective domains (Guston 2001, Cash 2001).

Boundary organizations have also been a focus of researchers and practitioners concerned with environmental management, including water resources and climate change adaptation. Cullen called the boundary between water science and water management “turbulent” due to conflicting views on the purpose of science, and called for more science brokers to play intermediary roles across the boundary (Cullen 1990). More recently, Feldman and Ingram and Kirchhoff, Lemos, and colleagues have studied how boundary organizations operate and enhance climate science communication to local stakeholders under the framework of the NOAA RISA program in the United States (Feldman and Ingram 2009, Kirchhoff et al. 2013, Lemos et al. 2014).

In many real-world contexts, there is not just one organization located between the science and the local user, but a chain of organizations. These “boundary chains” are thought to help provide “cover” and help “depoliticize the science” as they exist across multiple societal divides (Lemos et al. 2014). Recently, attention has been turned to better understanding how such boundary organizations support each other and come together to form chains (Kirchhoff et al. 2015). Lemos and her colleagues have distinguished between three different arrangements of boundary chains that demonstrate different aspects of the work they do (Figure 1.1). “Key” arrangements are those where the organization of interest helps connect different organizations to the overall network and “broadens the diversity of the users.” “Linked” chain arrangements are those where the organization is part of a chain that connect across a particular divide (such as between scientist and local users or between geographic levels) and provides translation or customization services. “Networked” arrangements help build boundary chain capacity by combining both “Key” and “Linked” arrangements and supporting connections between other groups (Lemos et al. 2014).

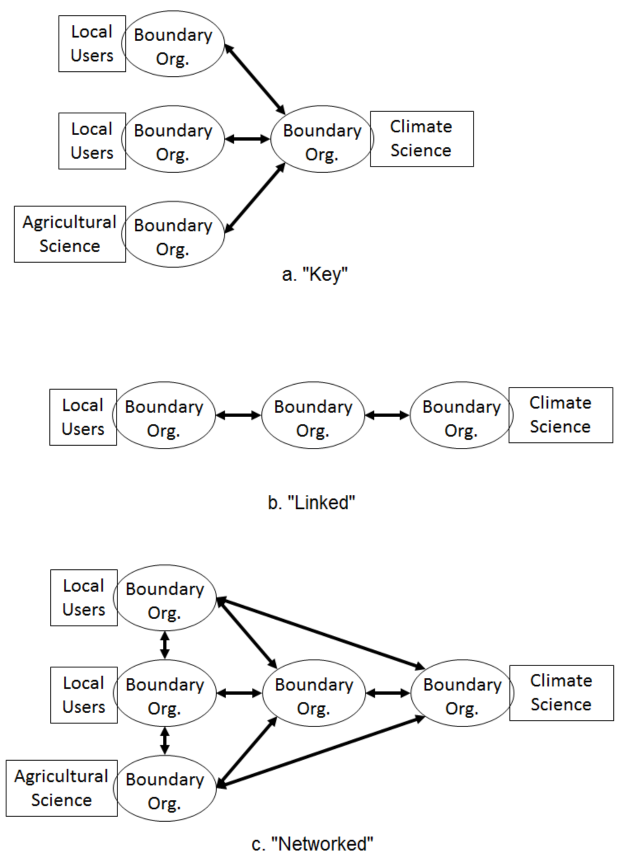

Figure 1.1 *Three types of boundary chain arrangements: a. “Key” chains that connect different groups; b. “Linked" chains that translate across societal divides; c. "Networked" chains that help create or strengthen group ties. “Climate Science” and “Agricultural Science” are used as examples of different areas of expertise that boundary chains can connect. Adapted from Lemos et al. 2014.*

1.4 Dissertation Outline

I had the opportunity to further explore these issues in two different study contexts: Guanacaste, Costa Rica and Montana, USA. Both areas are experiencing increasing demands on their water systems and novel stakeholder group interactions due to both climate and socio-economic changes. Table 1.1 provides a summary of the two case study regions. Table 1.2 summarizes the focus of the research work in each region.

Table 1.1 *Summary of Case Study Areas*

	Guanacaste, Costa Rica	**Montana, USA**
Climate Background	Semi-arid province with distinct rainy and dry seasons. Yearly precipitation patterns may be affected by changes in larger climate systems.	Large western state with multiple climate areas. Climate projections predict overall warmer climate with less precipitation in the form of snow, which is a major source of water storage.
Socio-economic background	Transitioning for last several decades from large ranches and locally-focused small holder farming to larger export-oriented farms, use of water resources for hydroelectricity production, and increased tourism.	Current population relatively evenly split between rural and urban areas but projected to dramatically shift towards urban. History of agriculture, lumber, and mining, which still play large roles alongside growing finance and other urban based economic activity.
Social Divisions	*Science/Local* • Fractured water governance has inhibited flow of information. • Local users feel science products are not scaled for them. • Non-participatory forecast creation. *Rural/Urban* • Public tensions between resorts, large farms and municipal system stakeholders related to water use. *Political* • Relative consensus on the reality and causes of climate change.	*Science/Local* • Local users feel science products are not scaled for them. • Some agriculturalists see scientists as having no practical experience. *Rural/Urban* • Population growth in urban areas while water rights remain with rural agriculturalists. • Concern that rural and urban areas are growing apart from each other culturally. *Political* • Climate change is seen as politically polarizing.
Stakeholder Groups and/or Boundary Organizations	Focus on stakeholders from the following groups: government agencies (including those responsible for municipal systems, agriculture, environment, and irrigation), hydroelectricity sector, small and large farmers, tourism sector, local water committees (ASADAs), and members of the public.	Focus on the NGO One Montana as active, important part of boundary chain. Other organizations connected to chain: Montana Climate Assessment (MCA), Montana Climate Office (MCO), Montana State University Extension, USDA Climate Hub, Montana Dept. of Agriculture, MT Stockgrowers Association, MT Farmers' Union, Agricultural Irrigators (AGAI), and individual farmers and ranchers.

Table 1.2 *Focus of research work in each study region.*

	Guanacaste, Costa Rica	**Montana, USA**
Focus of research	Exploring a water management context in which boundary organizations may be useful.	Examining a current in-practice boundary chain and why groups and individuals engage with the chain.
Research questions	1. How do stakeholder groups differ in their perceptions of the water system, responses to drought, and the use of improved hydro-climate information? 2. To what extent do different stakeholders trust the various sources of forecast information and what is the relationship between trust and the use of such forecasts?	1. What role does One Montana play in the boundary chains that connect climate scientists and agriculturalists? 2. What prompts organizations to engage with One Montana and its network? 2. What do members of the boundary chain network perceive as successful and unsuccessful ways of communicating climate-related information between scientists and agriculturalists? 3. What prompts individual ranchers to be willing to seek out further connection or “buy-in” to the climate adaptation boundary chain One Montana is a part of?

This dissertation is organized as follows:

Chapter 2 presents the first study in Guanacaste, which focused on comparing the mental models that different water-management related stakeholder groups regarding the water system and use of hydro-climate information. As a continuation of the work presented in Chapter 2, Chapter 3 presents the results of a follow-up survey-based study in the Guanacaste region focused on how trust in rainfall forecast providers is related to the use of forecasts of varying time periods. Chapter 4 presents a study in Montana focused on the network history and communication strategies of a boundary organization trying to connect scientists and agriculturalists in the state. The dissertation concludes in Chapter 5 with a summary of the common findings and recommendations from the three studies, and presents potential future research plans in these areas.

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II. COMPARING GROUP PERCEPTIONS OF WATER SYSTEMS AND HYDRO-CLIMATE INFORMATION

As part of the FuturAgua project, I had the opportunity to focus on the perceptions of different groups in Guanacaste related to the water system and climate information. Following the mental models approach outlined in Morgan et al. (Morgan et al. 2002), we decided to first do an exploratory analysis of the different group perceptions as a way of finding out about the contexts in which these groups operate. As researchers from outside of the region, this seemed like an appropriate and important first step off of which to base further research. Additionally, it was a way to add to the literature and the overall research project by comparing multiple stakeholder groups in one specific climate adaptation context. This chapter was published as an article in the online journal Earth Perspectives in 2016.[1] In collaboration with my co-authors, I conceived and designed the data collection and analytical plans. I handled interview logistics with the assistance of FuturAgua and local personnel, conducted the interviews, data analysis and wrote the draft paper.

Abstract

In the face of changing environmental and socio-economic drivers, access to, understanding of, and the use of probabilistic climate forecasts and other sources of scientific hydro-climate information are important for informed decision making in the water sector. This paper characterizes and compares local perceptions of the water system and hydro-climate information in the seasonally dry province of Guanacaste, Costa Rica. Semi-structured interviews were conducted with a total of 40 participants from a 7 water-related groups. Interview results were used to compare mental models of the drivers of water systems and water scarcity mitigation/adaptation options, and relate them to stakeholder information needs, accuracy ratings, and use. Our results suggest that: 1) while there appear to be similar perceptions of the drivers of rainfall and groundwater, there is a gap between groups in the use of forecasts, the awareness of management options, and the level of detailed understanding of how the water system works; 2) there are potential mismatches between the information presented in rainfall forecasts and the stated and/or salient information needs of some stakeholders, specifically in the case of groundwater resources; 3) there appear to be different perceptions of forecasts even among groups that rate the accuracy of such forecasts the same; and 4) there appears to be a relationship between the use of forecasts and certain types of management actions such as long-term planning. Our findings warrant further investigation and confirmation and may contribute to the development of communications that help stakeholders make informed decisions about freshwater management in semi-arid regions.

[1] Babcock, M., Wong-Parodi, G., Small, M. J., & Grossmann, I. (2016). Stakeholder perceptions of water systems and hydro-climate information in Guanacaste, Costa Rica. *Earth Perspectives*, *3*(1), 1-13.

2.1 Introduction

Background

Successful freshwater resources management is a complex task that involves diverse stakeholder groups and decision making at multiple spatial and temporal levels. Increasingly, changes in climatic patterns, socio-economic pressures, and other large-scale drivers of water systems have created (and are expected to continue to create) contexts in which older water management practices and decision-making strategies are not adequate to meet the demand for freshwater in multiple sectors. Experts, national governments, and international agencies have developed and promoted scientific hydrologic modeling and forecasting tools for use in integrated water resource management, and as part of adaptation plans for water systems under changing climate conditions (Stern and Easterling 1999). Scientific hydro-climate information refers to information that is derived from statistical and modeling analyses that incorporate uncertainty, unlike earlier or traditional approaches. However, it has been shown that many water managers from different sectors and geographic areas do not incorporate this information into their decision-making but rather continue to rely on traditional methods that were developed during (or which assume) a more stationary environment (Rayner et al. 2005; Kirchhoff 2012; Orlove et al. 2004). Without using such information, stakeholders' may not be making *informed* decisions – where the costs, benefits and uncertainties of choices are understood well enough to enable decisions to be made in accordance with values and preferences. This lack of informed decision making may contribute to maladaptive decisions for managing socio-ecological systems (SES), especially in arid and semi-arid areas of the developing world where water stress is already elevated and where institutional and physical resource constraints leave such systems more vulnerable to rapid social and ecological change.

A number of specific factors influence the use of scientific climate information in both wealthier and developing nations, including but not limited to: whether the information relates to local conditions and the scale at which the user is operating, the perceived reliability of forecasts and trust in the forecasting agency, the timing of the forecasts, the socio-economic status of the potential user, the specific sector of work the user was involved in, political differences between providers and users, forecast content and the form of communication, institutional standard operating procedures, and the perceived risk from current and future threats to water resources (O'Conner et al. 2005; Rayner et al. 2005; Orlove et al. 2004; Moser and Luer 2008; Letson et al. 2001; Hansen et al. 2004; Lemos et al. 2002). Key factors in the developing nation context include whether forecasts are perceived as appropriate and trustworthy, whether there is access to such forecasts, and whether there are resources to act on that information (Letson et al. 2001; Orlove et al. 2004; Lemos et al. 2002). Furthermore, each of these factors may influence decision making differentially depending on the decision contexts faced by stakeholders acting in different water use sectors (e.g. agriculture, domestic use, energy production, recreational, environmental protection). While it is clear that a number of factors influence the use of climate information, recent research suggests that not all factors are equally influential across all stakeholders. Indeed, a number of additional factors inherent to the decision maker (e.g., who they are; level of expertise/education) and external factors such as context (e.g., water sector decision) and goal (e.g., agricultural production, energy production, recreation, environmental protection) can influence whether a decision maker has access to and can or will make use of such information. Recognizing this, recent work calls for more work on identifying the decision making processes of stakeholder groups with respect to questions of climate adaptation (Krichhoff et al. 2013; Jain et al. 2015). Therefore, in this paper we ask: What do different groups of water end users think of scientific hydro-climate information and how, if at all, they use this type of information in their decision making.

Research Questions and Framework for Comparing Stakeholder Perceptions

Here we explore the perceptions of multiple stakeholder groups in Guanacaste, Costa Rica, that are facing increasing water stress in the face of a changing climate (Kuzdas 2012; van Eeghan 2011). To assess stakeholder perceptions in a systematic fashion, we developed a simplified framework (Figure 2.1) that incorporates concepts from Theory of Planned Behavior (Ajzen 1991), the Planned Risk Information Seeking Model (Kahlor 2010), and Protective Motivation Theory (Rogers 1983).[a] This framework takes as its end points the actual implementation of water management actions and/or seeking out and using hydro-climate information. In this framework, a stakeholder's decision to implement management actions is affected by the perception of a threat or opportunity that requires the action, the perception that they have the ability to implement the action, and/or the perception that there is a social pressure to perform that action. Similarly, whether they seek new information and/or use such information is affected by their perceived need for that information, ability to use it, and any subjective norms related to the use of that information. The use of new information in turn can affect the implementation of the management action. Underlying the stakeholder's perceptions of threats/opportunities, information needs, ability, and social norms are their perceptions of the water resources related social-ecological system and of the different aspects of the hydro-climate information.

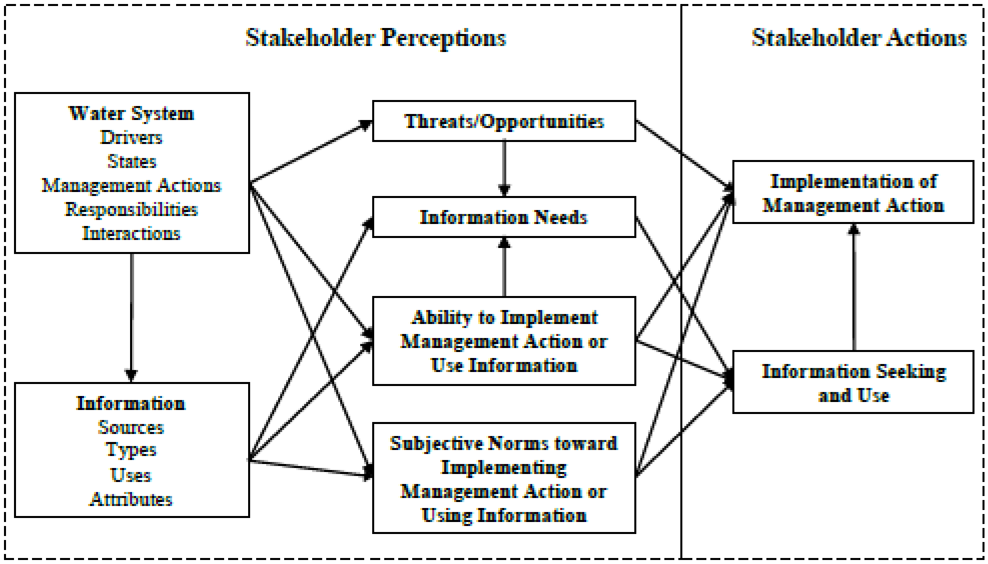

Figure 2.1 *Simplified stakeholder perceptions and decision making framework*

Our focus therefore is on the following main questions:

1. How do various stakeholder groups perceive the freshwater system in their local and regional areas? Specifically how do they perceive the system drivers, states, and responses within the system? What are the similarities and differences between stakeholder groups?
2. How do various stakeholder groups perceive and use hydro-climate knowledge and specific sources of information? Specifically, how do they perceive the information sources; the attributes of the information, including trustworthiness and accuracy; and whether and how the information is used for informing decisions? What are the similarities and differences between stakeholder groups?

The next section describes the study area and the development and implementation of the interview protocol. Section 3 describes the qualitative and quantitative results of the interviews, and Section 4 discusses the suggested implications of these results for water management policy in the region and how they may inform future work.

2.2 Methods

Study Area and Stakeholders

Freshwater Resources in Guanacaste, Costa Rica

This study is part of the FuturAgua Project in Guanacaste, Costa Rica, a multidisciplinary, multinational research effort supported by the G8 Belmont Forum to study climate change and freshwater security in developing nations (FuturAgua 2015). Guanacaste is a seasonally dry tropical province, with a yearly rainfall pattern that is typically comprised of a 6-month dry season from late November until May, a smaller rainy season from May to July, a mid-summer drought in July/August, and the main rainy season from August to November. This pattern is significantly affected by the status of the El Niño Southern Oscillation and the North Atlantic Oscillation climate systems. Climate change forecasts and models, such as those included in the Fourth and Fifth Assessment Report of the IPCC, predict changes to the annual cycle of precipitation and increased temperatures, both of which may additionally stress water supplies in the region (Rauscher et al. 2008; Rauscher et al. 2011; Karmalkar et al. 2011; Ryu and Hayhoe 2014; Neelin et al. 2006; Steinhoff et al. 2014).

Costa Rica guarantees a healthy environment to its citizens in the national constitution and has passed water related laws that establish that freshwater resources cannot be privately owned. The Water Directorate of MINAE, the Costa Rican Ministry of the Environment and Energy, manages concessions of groundwater and river water for use by municipalities, hydroelectric power facilities, and private entities such as farms, off-grid households, and resorts. Within the last 30 years, municipal population growth, changing agricultural activity, increased hydro-electric power production, increased tourism developments, and continuing environmental protection interests all have placed increasing demands on freshwater resources and there has been a recent history of inter-stakeholder group conflict over water issues (Ramírez-Cover 2008). These conflicts have been shown to occur in part due to underrepresentation of local stakeholders in decision making. In addition, there is a lack of credible or available scientific measures of water quality and quantity, and without these measures the ability to distinguish between the physical lack of water resources and misallocation of such resources has proven difficult (Kuzdas 2012 and van Eeghan 2011).

Stakeholder Groups

For this study we separate stakeholders into the following groups: government agencies, large farmers, small farmers, hydroelectric system managers, tourism businesses, village water committees called ASADAs, and the public. The government agencies that make decisions at a local and regional level about water resources or are impacted by such decisions include MINAE as mentioned above, the Ministry of Aqueducts (AyA), the Ministry of Agriculture and Livestock (MAG), and the Ministry of Subterranean Water and Irrigation (SENARA). AyA is mandated to provide potable water to all citizens in the country for domestic use. In the larger towns and cities, AyA manages the water systems, whereas in the smaller less-connected towns the water systems are managed by local water committees or ASADAs. The executive council of each ASADA are volunteers that are voted in by the users every 2-3 years (some ASADAs pay the administrators and technicians that work on the systems). The volunteer councils are legally responsible for maintaining the water systems and have the authority to collected water use fees, but typically have less technical expertise then the central AyA offices. Almost all municipal water systems in Guanacaste source their water from groundwater or rivers.

The Ministry of Agriculture and Livestock (MAG) is mandated to provide technical assistance to Small Farmers and this outreach includes assistance with irrigation and climate adaptation efforts. Small farmers are either tenants of Large Farms or family enterprises who either raise cattle or grow a variety of crops for local and sometimes export markets (rice and sugar, but also peppers, coffee and vegetables). Large Farms are large estates used either for cattle grazing or for the growing of cash crops such as rice, sugar, and/or melons and employ agronomic engineers as well as large numbers of laborers/tenant farmers. Large and Small farms typically use a mix of direct rainfall, groundwater, and river water depending upon their location and crop. Depending on the farm type they have a mix of irrigation methods installed on their property (this is more widespread on Large Farms, but Small Farms may also have their own systems). In special irrigation districts, SENARA is responsible for providing irrigation water to Small and Large farmers.

Hydroelectric power generation in Guanacaste comes from the ArCoSa system (3 plants in series for a total capacity of 360 MW) operated by the Costa Rican Electricity Institute or ICE, and a two plant system run by the rural electrification cooperative, COOPGUANACASTE. These systems are located in the mountainous region along the eastern border of the Province which receives a larger amount of yearly rainfall and use a mix of reservoir and river water.

Available Hydro-Climate Information

The main source of climate forecast information in the region is the Costa Rican National Meteorological Institute (Spanish acronym, IMN). The IMN provides daily and weekly weather forecasts through its website (IMN 2016). The IMN also provides for free on this website monthly climate reports that review the past months precipitation and temperature data and project future precipitation by region typically up to three months ahead (IMN also less frequently releases predictions for the next 6-12 months). Internet coverage in Guanacaste is relatively good and many access the internet through mobile devices (this is more true of younger generations). Additionally all of this information is also transmitted through local and national public media (TV, radio, and newspapers). The IMN also provides more detailed historical data to the public and other government agencies, though for a sometimes hefty fee. The other government agency that has direct access to climate measurements is ICE, though typically ICE does not share this information. ICE also has information regarding reservoir levels that is used in the management of hydroelectric power stations. Many Large Farmers have their own meteorological equipment and have access to NOAA forecast information. Streamflow and groundwater data are more difficult to come by and this lack of information about how much water exists in certain aquifers has been identified as a factor in local water conflicts (Kuzdas 2012 and van Eeghan 2011).

Interview Protocol

In order to elicit stakeholder perceptions, a variation on the mental models approach (Morgan et al. 2002) was employed. This approach includes the use of a formative semi-structured interview that aims to more broadly and openly elicit perceptions from participants. The results of this interview are then used to inform the development of surveys to confirm the prevalence of interview results and test hypotheses generated from the original interview (Klima et al. 2012). Typically this approach has been used to compare risk perceptions and facilitate risk communication between experts and laypeople (Morgan et al. 2002; Hansen et al. 2004). It has also been used to compare climate and adaptation perceptions across experts (Otto-Banaszak et al. 2011). In this study, the approach is used to help compare perceptions of water systems and climate information across multiple stakeholder groups.

Drawing from previous literature and input from other FuturAgua researchers during the winter and spring of 2014, the English language interview protocol was developed. It was then translated into Spanish by the lead author and edited for language by two native Spanish speakers (a coordinator from the FuturAgua project and a member of the local advisory group located in Nicoya, one of the main towns in Guanacaste). In May 2014, the protocol was pilot tested for understanding with two different members of the Nicoya advisory group (an environmental ministry employee and a university professor) prior to the start of the field interviews. The protocol was structured into three main sections: 1) open ended questions about stakeholder perceptions of the social-ecological system (SES); 2) open ended questions about perceptions of water system information and sources and closed questions rating the accuracy of mentioned sources; 3) specific questions about forecasts and climate change (the full protocol can be found in Appendix B).

Interview Participants and Process

A total of 40 participants were interviewed from 7 different stakeholder groups: Agencies (n=10, including government employees of AyA, MAG, MINAE, and SENARA), ASADAs (7), Small (6) and Large (4) Farmers, Hydroelectric power managers (3), Tourism-centered businesses (4), and members of the Public (6). Participants were recruited through a variety of strategies. Members of the Nicoya advisory group, other FuturAgua researchers, or government agency contacts suggested most of the participants and named them as either knowledgeable or interested individuals. Some ASADA members were contacted based on a list of contact information provided by the Aqueduct ministry (AyA) in Nicoya. Other ASADA members were recruited using snowball sampling, in which ASADA group interview participants were asked to name other ASADA members to be contacted. All participants from the Tourist and Public stakeholder groups were directly recruited as a convenience sample (Berg 2001) by the lead author in the street, shops, restaurants, businesses or hotels. All potential participants contacted were interviewed with the exception of two (1 hydroelectric project manager and 1 small farmer - both due to scheduling issues). The mix of convenience and snowball sampling in these types of studies is standard practice in the field (see Kirchhoff 2012 and Orlove et al. 2004 as examples), however one possible issue with proceeding in this manner is that the results may not include the views of individuals who live farther away from others or those who have less societal connections.

Interviews were conducted in Guanacaste during June and July 2014[b]. The interviews were recorded and conducted in Spanish except for one (an English-speaking hotel owner who was from the United States and did not want to be recorded). The interviews were performed one-on-one, though occasionally in some interviews there were interruptions and additional comments made by others (family members, neighbors, and in some cases one of FuturAgua's local advisers). Interviews lasted between 25 and 90 minutes, with most being approximately 45 minutes long. Participants were not monetarily compensated. After the interview, each participant was given a FuturAgua mug as a thank you gift (participants were not informed of the gift in advance of the interview).

The median age of interview participants was 54.5 years. Overall, 55% of the participants had at least a college degree. The percentage of stakeholders that had such a degree of education within the Large Farmer, Agency, and Hydroelectric groups was 90% or above, whereas the percentage in the other groups was 50% or below. Only 17% of the participants were female, which, while very low in terms of the general public and elected government positions, is closer to the percentage that are in ASADAs (20% based on AyA records) or that work for MINAE (25%) in Guanacaste. Recognizing that the intent of studies employing the mental models approach with in-depth interviews is to discover concepts and suggest hypothesis (not to test them), a sample that includes participants from the targeted groups was sought, but it did not need to be representative.

Coding and Analysis

All interviews were transcribed (Spanish to Spanish) either directly by the lead author or by transcribers recruited through Amazon Mechanical Turk, an Internet platform for crowdsourcing short "human intelligence" tasks (Amazon Mechanical Turk 2015). All Mechanical Turk transcriptions were checked for errors and corrected by the lead author. Interview transcripts were translated into English by the lead author and as a quality check several interview transcripts were then back translated from English to Spanish by native Spanish speakers from the broader FuturAgua research team.

The lead author used multiple iterations of an open-coding procedure (Strauss 1987) to inductively find common and interesting themes from the interview transcripts for further analysis. For the one interview that was not recorded, the lead author's notes from the interview were used as the transcript for coding purposes. The codes were separated into groups concerning drivers, states, and uses of the water system, actions taken to mitigate or adapt to water scarcity, and information sources and attributes (a full list of the sub-codes under these categories can be found in Appendix C).

QDA Miner Lite software (QDA Miner Lite 2015) was used to "tag" excerpts with one or more codes, allowing the grouping of similar quotes and descriptive comparisons of pairs of codes. A second rater coded a subset of 11 of the transcripts, and there was 69% agreement between the two raters as to whether a specific code was mentioned in a specific transcript. Literature on inter-rater reliability suggests that a percent agreement of 69% indicates “substantial agreement” (Landis and Koch 1977). The first coder conducted the interviews and thus likely had a more nuanced perspective of the transcripts and allocated more codes than the second coder. These statements have been added to the manuscript.

Binary frequencies of mention (mentioned in transcript versus not mentioned) were determined for each participant for each single sub-code (e.g., DRIVER-ELNINO) and for select pairs of sub-codes (e.g., did the transcript mention both INFOSOURCE-FORECAST and INFOATTRIBUTE-USED?). Pairing sub-codes allowed frequency counts of interactions such as Driver/State pairings. The percentage of participants within each stakeholder group that mentioned a certain sub-code or pair of sub-codes at least once was then calculated and used for comparing across stakeholder groups.

Transcript excerpts that mentioned the numerical rating of information sources were collected and analyzed with simple descriptive statistics. No inferential statistics were performed as the participants were not randomly selected and there were only a small number of participants in each of the different stakeholder groups.

2.3 Results

How various stakeholder groups perceive the freshwater system in their local and regional areas

Views on drivers of rainfall amount and duration and groundwater levels

The main sources of water for stakeholder use mentioned by interview participants from all groups were direct rainfall and/or groundwater (accessed through wells and/or aqueducts). Table 2.1 shows the perceived drivers of the amount and distribution of rainfall mentioned by interview participants. Global warming-related climate change was the rainfall driver identified by the highest percentage of members within the Agency, ASADA, and Tourism groups. Climate change and the effects of the El Niño Southern Oscillation (ENSO) were both mentioned by the highest percentage of members within the Small Farmer, Large Farmer, and Hydroelectric groups. Climate change was not mentioned at all by the Public as a rainfall driver, but ENSO, Deforestation, and God were tied for most mentions within this group. Climate change and ENSO were the most mentioned drivers across groups, followed by. Deforestation, Geological drivers, and unspecified Natural cycles.

Table 2.1 *Drivers of rainfall and groundwater levels mentioned by members of different stakeholder groups*

	% of stakeholder group members mentioning specific driver						
Rainfall Drivers	**Agency (10)**	**ASADA (7)**	**Sm. Farmers (6)**	**Lg. Farmers (4)**	**Tourism (4)**	**Hydroelectric (3)**	**Public (6)**
Climate Change	**40%**	**43%**	**50%**	**50%**	**50%**	**67%**	0%
ENSO	20%	29%	**50%**	**50%**	0%	**67%**	**17%**
Nature	10%	14%	0%	25%	25%	0%	0%
Deforestation	0%	0%	33%	25%	25%	33%	**17%**
Geological/Geographical	20%	0%	33%	**50%**	25%	33%	0%
Ozone Destruction	0%	0%	0%	0%	25%	0%	0%
God	0%	0%	0%	0%	25%	0%	**17%**
Groundwater Drivers							
Rainfall	20%	**29%**	**50%**	**50%**	0%	0%	0%
Climate Change	20%	**29%**	0%	0%	0%	0%	0%
ENSO	20%	14%	0%	25%	0%	0%	0%
Geological/Geographical	10%	**29%**	33%	25%	0%	0%	**33%**
Deforestation	**30%**	14%	0%	0%	0%	0%	0%
Population Growth	20%	0%	17%	0%	0%	0%	0%
Tourism Use	20%	14%	17%	25%	0%	0%	0%
Large Farm Use	**30%**	14%	0%	0%	0%	0%	0%
Other Population	0%	14%	17%	0%	0%	0%	0%
Misuse	20%	0%	0%	0%	0%	0%	0%
Damage	10%	0%	0%	0%	0%	0%	0%
God	0%	14%	0%	0%	0%	0%	0%

Bolded values represent the drivers mentioned by the highest percentage of members within the group.
() indicate the number of participants in each group.
Specific driver definitions can be found in Appendix C

Table 2.1 also shows the percentage of each stakeholder group that mentioned different drivers of groundwater levels. Hydroelectric managers did not mention (and were not asked about) groundwater drivers during the interviews, most likely because the source of water for their facilities comes from rivers and reservoirs. Tourism group members also did not mention groundwater drivers, which is of potential interest as the source of water for some of these members is groundwater and some of the political conflict in the region has been over tourist use of aquifers (Kuzdas 2012 and van Eeghan 2011). The most mentioned driver of groundwater resources by several groups was the amount and timing of rainfall. This association clearly has a strong physical basis, especially for shallow (surface) aquifers and wells. The broadest range of drivers were mentioned by the Agency and ASADA group members, which may be a function of the fact that these two groups mentioned groundwater the most out of any other group in general.

Participants mentioned both perceived direct and indirect drivers of rainfall and groundwater levels. A partial explanation for these results comes from the fact that different participants expressed different levels of specificity and sophistication when discussing these issues. For example, the two quotes below show different levels of detail and knowledge about the role El Niño plays:

> *"Depends if it is El Niño or La Niña, and it is a little complex and everything but the El Niño is because of the heating of the Equatorial Pacific Ocean… the climate variability that is a normal process. El Niño has always existed, La Niña also...It's that the storms on the Pacific side, when it rains a lot 5 days, 7 days, 15 days (is when) the Pacific wind tries to go toward the mountain system and it rains a lot. But this year less will be seen, it is expected that 45% less storms in the Pacific and the wind is hitting here makes it that the humid breeze from the Pacific backs off and it doesn't rain." (Agency 10)*

> *"Yes. Well they say (there is drought) because of the El Niño phenomena. I don't know when it will be. I don't know." (Public 5)*

In general, the participants from the Large Farmer, Hydroelectric, and Government Agency groups were more specific and more confident in describing the relationship between global climate change, the El Niño system, and rainfall than were participants from the other groups.

Views on the state of water resources and appropriate management responses to lack of water resources

Most participants mentioned that they had enough water at the time of the interview to meet their needs. But, many participants also mentioned that they knew of other areas that did not, or expressed concern and/or uncertainty over whether they would have enough in the future. Table 2.2 shows the management options mentioned by each stakeholder group for addressing current or future water shortages (additional information about each option can be found in Appendix C).

Table 2.2 *Management actions for water shortages mentioned by members of different stakeholder groups*

	% of stakeholder group members who mentioned specific management action						
Management Actions	**Agency (10)**	**ASADA (7)**	**Sm. Farmer (6)**	**Lg. Farmer (4)**	**Tourism (4)**	**Hydroelectric (3)**	**Public (6)**
Nothing can be done	10%	29%	0%	25%	25%	33%	**50%**
Store water	10%	0%	0%	0%	**50%**	0%	33%
Increase efficiency	50%	29%	17%	75%	25%	0%	33%
Standard operations	30%	**57%**	0%	25%	**50%**	0%	33%
Use improved tech.	30%	14%	33%	**100%**	0%	0%	0%
Buy crop insurance	0%	0%	17%	25%	0%	0%	0%
Modify planning	**90%**	0%	17%	**75%**	25%	**100%**	17%
Change mentality	30%	**57%**	33%	50%	25%	33%	17%
Make new law/rule	20%	14%	0%	0%	0%	0%	17%
Protect watershed	40%	**57%**	33%	25%	25%	67%	0%
Find new supply	70%	43%	**50%**	50%	25%	33%	33%
Reforest	40%	71%	33%	25%	25%	67%	17%
Megaprojects	40%	0%	0%	0%	0%	0%	0%

Bolded values represent the drivers mentioned by the highest percentage of members within the group.
() indicate the number of participants in each group.
Specific action definitions can be found in Appendix C.

At least one member of each group mentioned changing the mentality of users and society to be more environmentally friendly, reforestation actions, and finding new water supplies as responses to not having enough water. Table 2.2 also shows that the more frequently mentioned (and therefore assumed to be most practiced) management options varied by stakeholder group. For example, for Agency, Large Farmer, and Hydroelectric group members, the most mentioned options were grouped under the code "Modify planning" which encompasses changing longer term operations such as the design of future municipal projects or hydropower facilities, phasing out crop types, or expanding agricultural enterprises

Buying insurance as a response to a lack of water resources was only mentioned by farmers, who have experience with the various institutional crop insurance products offered by the government and through cooperatives. One Large farmer (Lg Farmer 1) mentioned an interesting complicating policy factor related to the timing of the rainy season: in order to get crop insurance, farmers have to plant before a certain date. If this date is set too early in a year with a late rainy season then the insurance system may incentivize farmer decisions that result in additional crop loss.

Modification of planning activities (encompassing activities such as changing planting times and power generation schedules) was mentioned by a majority of members of government agencies, hydroelectric managers and large farmers and a minority of other groups.

Stakeholder perceptions and use of hydro-climate information

Perceived Information Needs

A total of 26 participants directly answered the question, "What would you like to know about the state of water resources that you don't already know?" The most common answer (9 participants) was related to how much water was in the aquifer of interest to that participant (including how much was in the aquifer now, how the groundwater flowed in or out, and how much would there be in the future). The main reason given for wanting this information was so that they would know if there was going to be enough water for their own use and the use by others. Other direct answers included, in order of frequency, information about groundwater quality (what was the quality and how to treat the water - 5 participants), information about climate change (forecasts and sources – 4 participants), what the rain forecast was going to be (3), information about surface water quality (3), and what the impact of climate would be on plants (2).

Awareness and Use of Different Types of Forecasts

During the interviews rainfall forecasts of four different types were mentioned: basic daily/weekly radio/TV/internet forecasts, seasonal 3-month/6-month forecasts created by the **IMN** or by ICE, year-long forecasts, and multi-year forecasts. Figure 2.2 shows that only a few participants mentioned multi-year forecasts, members of the Public group only mentioned daily/weekly forecasts, and the highest percentages of use of forecasts were for seasonal forecasts.

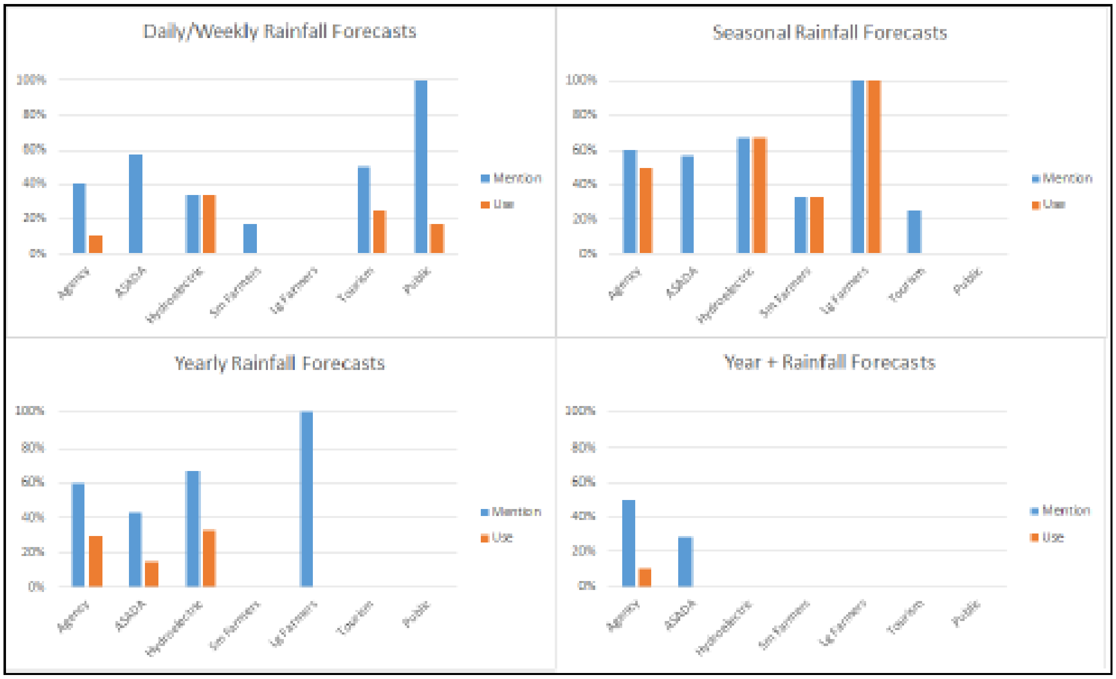

Figure 2.2 *Percentage of each stakeholder group that mentioned forecasts of different types*

3.2.3 Perceptions of Rainfall Forecast Accuracy

The most consistently mentioned information source related to water resources in Guanacaste was the short-term (weeks) and long-term (months/years) forecasts of rainfall provided by the IMN. The forecast accuracy was judged on a scale from 0 (completely inaccurate) to 10 (fully accurate). Based on participants' comments, the main reasons for high ratings were that the participant thought that the forecast matched what the participant actually experienced and that the people in charge of making the forecasts were skilled professionals/experts. As some participants put it:

> *"Like I said it is a trusted source, they take a lot into account. Maybe we don't make decisions only based on what they say but yes it forms an important part of the decision we make on our farm." (Lg Farmer 1)*

> *"Okay based on the last 3 years' experience I would say very good precision for example from 1 to 10 I would put a 9. At least in that they have said, "Here comes a dry period" and it is certain that there have been dry years. For example, this year…they predicted that May, June, and July were going to be dry but the percentage in June was drier than they thought it was going to be. Nevertheless yes they were right that there were dry months. I really… I have trust in the IMN" (Agency 10)*

Even participants who had a positive opinion on the accuracy of the forecasts usually also discussed some limitation to them:

> *"I would give between a 7 and 8. For example it fails. So they say in these 3 months it is going to rain 100 mm, 25-50-25, but maybe it rains 100 but 5-70-25, you understand that, or the total rain is more or less certain. I believe it is impossible that they do it so... In this they are not certain but it works very well." (Lg Farmer 1)*

> *"No, I give them a 7 about there, yes, yes, yes. But for the 3 month forecasts. They that make these (forecasts) take data from the different meteorological stations. So, to 3 months it is close enough with the projection, but equally they also are very responsible to say that for example the projections for 1 year are not as confident because in reality they are variable or so uncertain that it is a projection nothing more." (Hydroelectric 1)*

Participants often mentioned a mismatch between the spatial and temporal scales of the forecasts and the information they need to assess their water management decisions, and many participants mentioned that the farther into the future the forecast goes, the less accurate it will be. The reason for the spatial discrepancy that was most mentioned was that forecasts are given on the scale of the entire region, not on the scale of the sub-region, town, or farm level. Some participants from the Large Farmer and Agency groups stated that while 3-month-ahead average rainfall forecasts were useful, having a forecast that could describe the distribution of rainfall over those 3 months would be even more helpful.

For those assigning low accuracy ratings, the main reasons given included that the participants felt the forecast did not match what they actually experienced or more generally that reality was too variable for the forecasts to be accurate. As one participant said:

> *"They are not trustworthy. Sometimes they say it is going to rain in the afternoon and it is dry, sometimes they hit the target and sometimes they don't." (ASADA 7, rated accuracy of 5)*

This last quote and the quote from Agency 10 are representative of several that basically say, "Sometimes what the forecast predicts occurs, and sometimes it doesn't." The results show that whether this statement is used to justify a high rating or a low rating varies across stakeholder groups – it seems that large farmers, government agencies, and hydroelectric managers give high ratings and other groups give low ratings (see Figure 2.3).

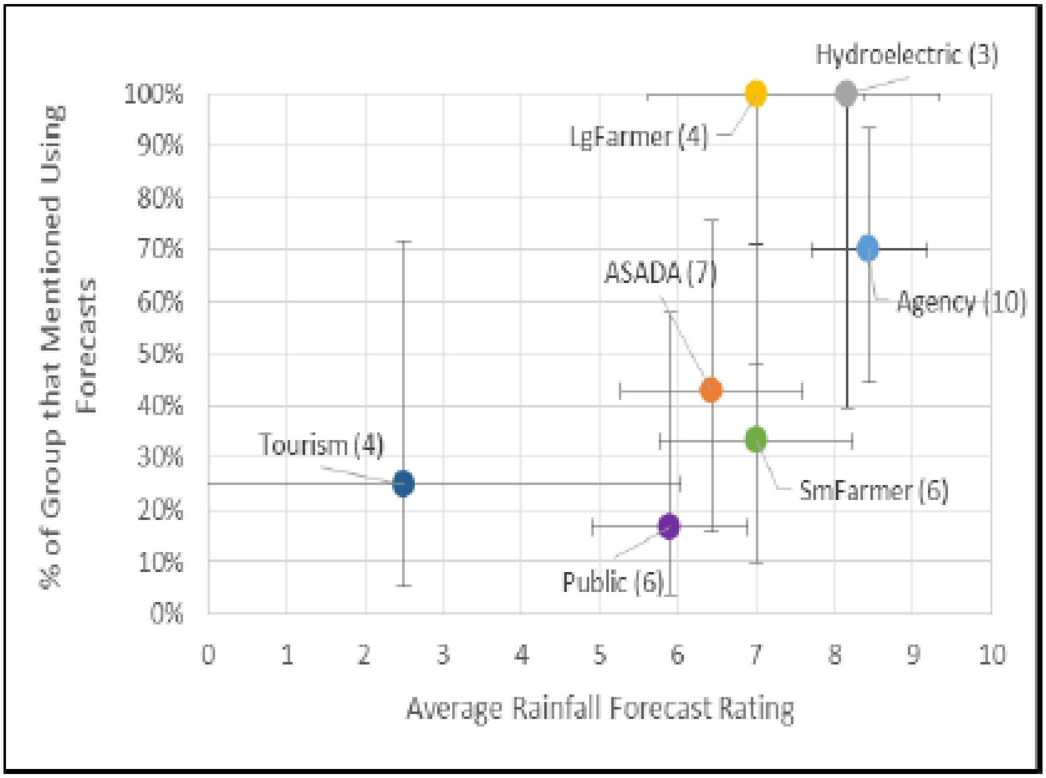

Figure 2.3. *Percentage of group that mentioned using forecasts vs. Average Rainfall Forecast Accuracy Rating Horizontal error bars are 2 SD. Vertical error bars are 95% CI on binomial p distribution. The (#) is the total sample size in the group used to calculate the % of group that mentioned using forecasts. The average rainfall accuracy is averaged only over those participants in each group that gave a numerical rating (and therefore can be less than (#))*

Use of Rainfall Forecasts

Figure 2.3 also shows the average rainfall forecast accuracy rating calculated for each stakeholder group compared against the percentage of group members that mentioned using the forecasts. The results suggest that higher average accuracy ratings for rainfall forecasts are associated with a greater stated use of such forecasts, though significant variation is present within groups. This tendency would be in agreement with previous results: Orlove et al. (2004), in their study of the fishing sector in Peru, similarly found that their results, "supports the long-established claim that perceived accuracy influences forecast use" and that, "subpopulations differ significantly in their use of this information".

The results presented in Figure 2.3 also may suggest that Large Farmers, Hydroelectric Managers, and Government Agency group members use rainfall forecasts more than ASADAs, Small Farmers, and members of the Public and Tourism industry. It also tentatively suggests that while Small Farmers and Large Farmers provided similar accuracy ratings for the rainfall forecasts, the percentage of group members mentioning using forecasts may be much higher among Large Farmers than among Small Farmers. This may be due to the Large Farmers potentially having more access or awareness of different types of rainfall forecasts.

More widespread use of forecasts within a group may be related to whether those forecasts are used to inform the modification of planning activities (changes in planting or equipment schedules, changes in energy production, etc.). Figure 2.4 shows that again there appears to be a distinction between Large Farmers/Hydroelectric Managers/Government Agencies and the other stakeholders, with the groups reporting the use of forecasts also reporting planning modification options for their water systems. These results could suggest either or both directions of influence: that these groups are responding with modifying planning activities because they use forecasts, or that they seek out and use forecasts because they are already modifying longer-term activities.

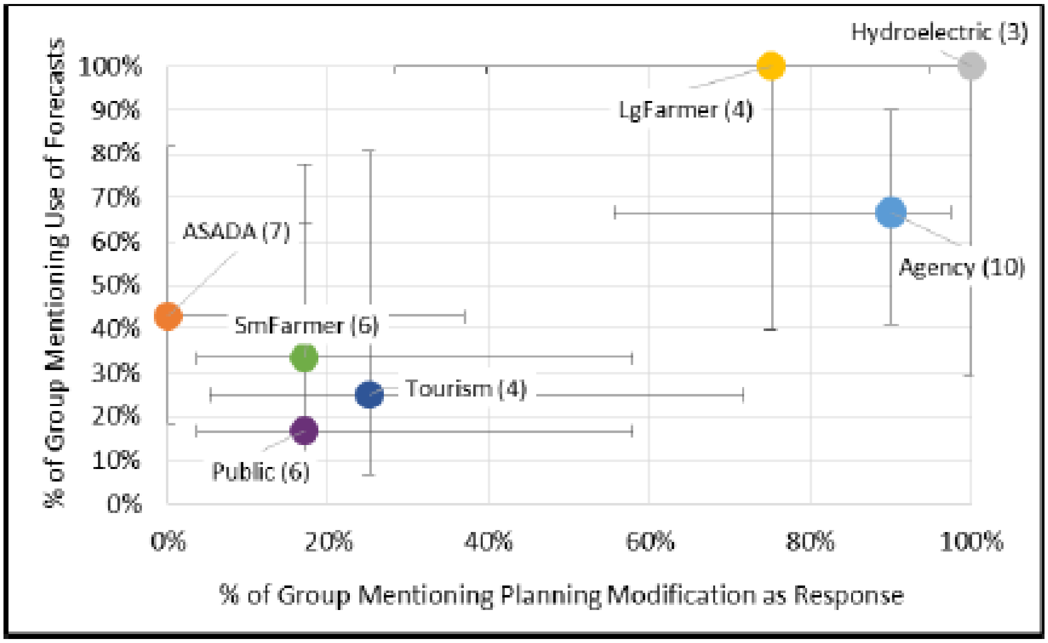

Figure 2.4. *Percentage of Group Mentioning Planning Modification Type Responses vs. Average Rainfall Forecast Accuracy Rating Horizontal and vertical error bars are 95% CI on binomial p distribution*

2.4 Discussion and Conclusions

Main Research Findings and Study Limitations

Our results suggest that most stakeholder groups are similar in their identification of climate change and ENSO as the major drivers of rainfall and groundwater resources, though they differ in their ability to explain the interactions between drivers and water resource states. Stakeholder groups also differ in the types of management responses they are most aware of, with some groups (Large Farmers, Hydroelectric, and Agency members) emphasizing longer-term planning. The timing of the rainy season and the amount of rainfall during the rainy season were identified as important factors in the water system, though individual stakeholders differed to a large extent in their awareness of different rainfall forecasts, their rating of forecast accuracy, and their mentioned use of forecasts. Participants from the Large Farmer, Hydroelectricity, and

Government Agency groups rated forecast accuracy as higher and mentioned using forecasts to a larger extent than other groups.

As this study is based on a limited number of interviews, the results presented above should be considered tentative and the actual prevalence of these beliefs and actions requires further testing with larger populations. Also, the results are all self-reported and therefore in some cases may not be accurate. In addition to working with larger populations, the use of other corroborating evidence (census and ministry information and observations, network analysis etc.) will help increase the confidence in these results and their usefulness.

Implications for Policy and Future Research

Our results tentatively suggest a split between two groups of stakeholders in the sophistication and specificity of descriptions of the interactions between water resource drivers, states, and management actions, in the perception and use of rainfall forecasts, and in the variation of opinions expressed on these issues within each group. This is important because as shown in the framework in Figure 2.1, these perceptions impact whether a specific threat is perceived and whether the stakeholder perceives they have the information and the ability to act in the face of this threat. Stakeholder groups we call the Large type (the Agency, Large Farmer, and Hydroelectric stakeholder groups) seem to express a clearer and more descriptive understanding of the physical drivers of rainfall and groundwater, use rainfall forecasts to a larger extent, and have less variation in their opinions than groups from the Small type (Public, Tourist, Small Farmer, and ASADA)[c]. In addition to differences in education levels, one general distinction between Large and Small groups that may factor into these results is that the Large groups most likely have more direct institutional connections and longer term relationships with the National

Meteorological Institute. For example, while the IMN releases its 3-month and El Niño forecasts publically on their website, and such forecasts are mentioned in the public media, only members of the Large Farmer, Hydroelectric, and Agency groups mentioned having direct meetings and specialized presentations with the IMN. These types of connections have been identified in previous literature as beneficial to the use of forecasts, specifically the "Interaction" part of Lemos et al.'s "Fit, Interplay, and Interaction" model (Lemos et al. 2012). "Interaction" opportunities that improve the use of forecasts such as co-production, long-term relationships, and two-way communication, appear to be more prevalent between Large Farmers, Agency, Hydroelectric groups and the IMN. The split in perceptions of the water system between Large and Small stakeholders may become problematic in cases where Large and Small groups interact, as in the case where the Ministry of Agriculture (MAG) is mandated to provide education and guidance on climate change and water management to small farmers. A similar relationship exists between the ASADAs and the Ministry of Aqueducts (AyA). An important implication for policy is that the educational material and communication practices of Large groups, should be developed and tested with Small groups to ensure understanding and usability of information to enhance the management of freshwater resources (Wong-Parodi et al. 2014).

Previous literature has emphasized the importance of providing information that helps answer the questions stakeholders actually have to deal with/are aware of (Moser and Luer 2008; Lemos et al. 2012; Fischhoff 2013). For example, in Moser and Luer's study of coastal managers (2008), they argue that, "the overarching message emerging from the information needs identified by coastal managers is that climate change science still needs to be translated into types of information that are salient to the manager". Our results suggest that rainfall and climate forecasts are not being translated into information about the more salient water resource concern, which in this case may be groundwater (based on the interest expressed in obtaining additional information about it as mentioned in Section 3.2.1). In our results, while rainfall was perceived as a major driver of groundwater, information on groundwater levels and flows was directly identified as a need more often than climate and rainfall forecasts. If groundwater levels are information that people want and need in the study area, then perhaps communicators of climate information need to be able to do a better job of translating climate forecasts into a type of groundwater forecast (the feasibility of which depends greatly on how well the groundwater, surface water, and precipitation interactions are monitored and understood). If modeling of the groundwater levels or storage is too difficult to achieve this translation, then an alternative would be to try to understand better and communicate to stakeholders how increased groundwater withdrawals during dry periods can exacerbate the effects of rainfall deficits on groundwater (a total of 7 interview participants from the Agency, ASADA, Small Farmer, and Large Farmer groups mentioned the relationship between the lack of rain and increased withdrawals as causes for concern). Future exploration and testing of stakeholder's understanding of the relationship between rainfall and groundwater levels may also assist in designing more salient and effective communication of climate forecast information.

An unexpected finding from the interviews that suggests an opportunity for further policy analysis and improvement is that crop insurance mandates regarding when planting must start may incentivize farmers not to adjust their planting schedules to changing rainfall patterns, resulting in crop loss. This finding suggests future work should include attempts to determine how important insurance is to farmers in the region (e.g., through follow-up surveys). If found to be important, then the process by which the providers of crop insurance determine their cutoff dates should be reviewed and possibly updated.

Looking across Figure 2.1 at how perceptions of information may influence the ability to use such information (and the subsequent use of that information), the differences between groups in the rating of forecast accuracy, whether forecasts are used, and how they are used suggest some additional questions about stakeholder decision making that could be tested in the Guanacaste and other contexts as part of future work. While it could be that the distinction between Large and Small type group stems solely from the inability of smaller groups to act due to the lack of opportunity or resources ("nothing can be done" was the most mentioned response for the Public), the fact that members of the ASADA, Small Farmer, and Tourism groups did mention actions that they take which could potentially be enhanced by forecast information (see Table 2.2) may indicate that other aspects are important. For example, signal detection theory, combined with an understanding of how stakeholders differ in their prior beliefs and motivational biases, could be used to better explain the finding that groups which basically agree on the fact that forecasts are not entirely certain rate the forecast accuracy differently (Green and Swets 1966; Small et al. 2014). It could be that the two groups see the distinction between how well the forecast matches reality the same way (same sensitivity), but one group's decision point for calling something "accurate" (different biases) and having a subsequent positive feeling about the forecast is higher or lower than the other's decision point. Another explanation for the discrepancy could be that some groups simply understand the forecast information or the underlying ideas of uncertainty less than others. Future studies that directly test such understanding may help determine if this is the more important determinate of accuracy perception. A different avenue to pursue based on our results involves exploring why the 3-month/6-month rainfall forecasts were the most well known and most used of the various types of forecasts used. For example, it could be that the perceived ability to use these types of forecasts is high because these forecasts fit the already established management schedules of different stakeholder groups (planting seasons, energy production projections, etc.).

Conclusions and Next Steps

Our findings support existing literature that those who have more resources (e.g., economic resources, organizational connections, etc.) are also those who tend to use forecasts (Lemos et al. 2002; Kirchhoff 2013). Similarly, those who rate forecasts as more accurate also somewhat tend to use forecasts more as mentioned above (Orlove et al. 2004). We also find that other factors may be important such as recognition of groundwater levels in people's understanding of water availability, the potential for crop insurance to provide perverse incentives, and the differences in perceptions of forecast accuracy between different stakeholder groups. Indeed, these findings warrant further investigation and confirmation and may contribute to the development of communications that help stakeholders make informed decisions about freshwater management in Guanacaste and other semi-arid regions.

Endnotes

[a] There have been attempts to integrate these various factors into summary frameworks such as Lemos et al.'s model of "fit, interplay, and interaction" which concentrates on the interaction between climate information providers and end-users (Lemos et al. 2012). Others have investigated these factors (and factors related to adaptation decision making and activity in general) using modified versions of established decision making, information seeking, and behavior frameworks such as the Theory of Planned Behavior (TPB) (Ajzen 1991), the Risk Information Seeking and Processing (RISP) model (Griffin et al. 1999), the Planned Risk Information Seeking Model (PRISM) (Kahlor 2010), and Protective Motivation Theory (PMT) (Rogers et al. 1983). For example, Truelove and colleagues use a modified version of the PMT they named the Risk, Coping, and Societal Appraisal (RCS) framework to study adaptation to climate change in the farming sector (Truelove et al. 2015) and Yang and colleagues have used RISP and PRISM to investigate and compare the seeking out of climate information between different groups (Yang et al. 2014a; Yang et al. 2014b). These frameworks all tie into the idea that in order to improve informed decision making, producers of scientific information must identify the specific decisions, perceptions, and decision environments faced by those stakeholders (Fischhoff 2015). [b] It should be noted that while most often this time of the year would have been the beginning of the wet season in Guanacaste, in 2014 this period was very dry and the government was in the process of issuing El Niño alerts (which may have primed some participants to bring up El Niño during the interview). [c] It should be noted that 2 of the 3 Hydroelectric group participants also work at government agencies.

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III. TRUST AND THE USE OF FORECAST INFORMATION

Based on our results from the first study, we were interested in performing a follow-up survey to confirm some of the results of the first study with an emphasis on the use of rainfall forecasts. In our original analysis we had combined many of the perceptions of different types of forecasts and had learned a little bit about who different groups trusted and why. Originally, the main focus of this study was to continue to compare different stakeholder groups on their use of different types of forecasts and who they trusted, but I was not able to collect a large enough number of surveys to perform a helpful group to group comparison. We decided therefore to instead use the data to strictly explore the differences between factors associated with the use of forecasts of different time frames with a focus on the issue of trust in forecast information providers. In collaboration with my co-authors, I designed the data collection and analytical plan. I implemented the survey both online and in the field, conducted the data analysis, and wrote the draft article. This chapter is currently being revised in preparation for submission to a journal.

Abstract

Weather and climate forecasts are promoted as ways to improve water management, especially in the face of changing environmental conditions. However, studies indicate many stakeholders who may benefit from such information do not use it. This study sought to better understand which personal factors (e.g., trust in forecast sources, perceptions of accuracy) were important determinants of the use of 4-day, 3-month, and 12-month rainfall forecasts. From August to October 2015, we surveyed 87 stakeholders in Guanacaste, Costa Rica about their forecast use. The result of an exploratory factor analysis suggests that trust in "informal" forecast sources (traditional methods, family advice) and in "formal" sources (government, university and private company science) are independent of each other. The result of logistic regression analyses suggest that 1) greater understanding of forecasts is associated with a greater probability of 4-day and 3-month forecast use, but not 12-month forecast use, 2) a greater probability of 3-month forecast use is associated with a lower level of trust in "informal" sources, and 3) feeling less secure about water resources and regularly using many sources of information (and specifically formal meetings and reports) are each associated with a greater probability of using 12-month forecasts. These results suggest that while forecasts of all times scales are used to some extent, decisions to use 4-day and 3-month forecasts appear to be more intrinsically motivated (based on their level of understanding and trust) while the use of 12-month forecasts seems be more motivated by a sense of requirement or mandate.

3.1 Introduction

Formal weather and climate forecasts are promoted as ways that various stakeholders – from farmers to municipal water managers – can improve their water resource management practices, especially in the cases where traditional methods of predicting weather and climate are no longer reliable due to rapid and unfamiliar environmental change. Unfortunately, much research has shown that there remains a gap between the amount of more reliable information available and the use of that information by decision-makers on the ground (Lemos 2012). There is a large volume of literature on the economic, organizational, and psychological factors thought to be associated with the use of formal forecasts in many water-related sectors and why water managers do not seem to take advantage of such tools (for summaries see Kirchhoff et al. 2013, and Dilling and Lemos 2012). This literature has shown how different factors are associated with the use of a specific forecast in a specific area, however few studies compare such factors and the use of forecasts of different timescales within the same context (see Hu et al. 2006 as an example of this). Therefore, in this study, we seek to expand on previous studies by exploring and comparing factors that may explain the use of different forecasts within the same geographical and decision making context.

Weather and Climate Forecasts for Water Management

Formal forecasts are made by international, national, and regionally weather and climate agencies and NGO institutions over a range of important time frames. There are daily and weekly weather forecasts that usually range from 1 to 14 days in advance and there are climate forecasts that range anywhere from months to centuries. The literature on forecast use is somewhat inconsistent in whether these various forecasts are labeled as long-term or short-term.

Following both Hu et al. (2006) and Whateley et al. (2015), we use the label "short-term" to refer to forecasts that predict 1 to 14 days into the future and "long-term" to refer to predicting 3-12 months. Short-term forecasts can provide helpful information to a variety of decision contexts ranging from the mundane and personal ("Should I take my umbrella to work?"), to the commercial ("Should I change my tour route?", "Should I apply fertilizers or pesticides today?"), to the larger-impact areas of flood control and hydroelectric energy production ("How should we operate our dam today?"). Longer-term forecasts on the order of months to years can provide information that assists with planting decisions, hydroelectric power production, whether to prepare for a near-term drought, etc. Multiyear to decadal forecasts can be used to inform long-term economic and environmental policies and large-scale infrastructure investments. As regions experience increased environmental and/or socio-economic change, decision makers may need to take into additional consideration forecasts of different lengths when managing water resources. For example, more erratic weather may increase the importance of short-term forecasts in an area concerned with flooding while an overall drying climate trend may necessitate the use of longer yearly forecasts to better manage longer-term municipal or hydroelectric water storage systems.

What influences long-term forecast use?

The majority of the literature on what influences the use of forecasts in water management focuses on the use by either government water supply managers or farmers of what are called seasonal climate forecasts (SCFs). There is some ambiguity in the way this term is used but it refers to forecasting periods of 3 to 12 months. Many studies in both higher income (e.g. O'Connor, 2005; Hu et al. 2006; Rayner et al. 2005, McCrea et al. 2005, Marshall et al. 2011, Whateley et al. 2015) and lower income (e.g Letson, et al. 2001; Orlove et al. 2004; Lemos, 2002, Patt 2006, Ingram et al. 2002) countries have shown that a wide range of specific factors that are associated with or influence the use of SCFs in water-related decision making. These factors relate to aspects of the potential user of the forecast (their status and resources, their perceptions and understanding about forecasts), the provider of the forecast and their interaction with the user (are they creating salient information and enabling good communication), the nature of the forecast itself (accuracy, scale) and its presentation (how is uncertainty dealt with), and the decision context in which the user finds themselves.

Some have investigated these factors using modified versions of established decision making, information seeking, and behavior psychology frameworks such as the Theory of Planned Behavior (TPB) (Ajzen 1991), the Risk Information Seeking and Processing (RISP) model (Griffin et al.1999) the Planned Risk Information Seeking Model (PRISM) (Kahlor 2010), and Protective Motivation Theory (PMT) (Rogers et al. 1983). More specific to the use of rainfall forecasts, Hu et al. (2006) used a TPB framework to study farmers in Nebraska, finding that use was affected by several social group pressures and that both perceived forecast accuracy and the perceived reliability of forecast providers served as barriers to use.

Others have used more institutional/organizational type frameworks. Cash et al. (2006) introduced the “saliency, legitimacy, and credibility” framework and Lemos et al. (2011) introduced the “fit, interplay, interaction” framework both of which emphasize that in order to be used, forecast needs to be fit to the decision context but not in a way that would make them inaccurate. Both frameworks also lead to similar conclusions that a co-productive relationship between the producer and user of such forecasts is paramount in many contexts as it helps ensure that the forecast is useful, able to be used, and accurate.

Patt (along with others), also emphasizes the importance of trust in the use of seasonal forecasts: trust that users have in the forecast (its accuracy), trust they have in the providers ability or intent, and trust that providers have in users ability (e.g., Patt 2006, where one forecast provider did not trust that the farmers could understand a certain type of forecast when they could and therefore provider a less informative and ultimately not used forecast). As interactivity between providers and users becomes more apparent and/or more important how to build and maintain trust has become an important factor in increasing the use of forecasts (Patt 2006, Lemos 2002, Kirchhoff et al. 2013).

Other more specific factors that are incorporated heavily into the above mentioned frameworks include institutional barriers/lack of incentives to use forecasts (Rayner et al. 2005), feelings of being at risk and therefore needed to do something about water resources (O'Connor et al. 2005), and the level of understanding of the forecast (McCrea et al. 2005, Letson 2001).

What influences short-term forecast use?

In contrast to the literature focusing on SCFs, the literature focusing on the use of short-term forecasts appears to be sparser. Previous research on the determinants of the use of short-term non-hurricane/tropical storm rainfall forecasts conducted in the US has found that weather salience, or the degree to which weather is psychologically important to an individual, is an important predictor of the use of such forecasts for planning daily activities (Stewart et al. 2012). Stewart et al. also found that salience was positively associated with the perception that weather information was important and with higher confidence in the forecasts. Related research by Demuth et al. (2011) found that the perception that such forecast information was important was associated with their use of the forecast for leisure, work, and dress activities and decisions. In their study focusing on both short and long-term forecast use, Hu et al. (2006) found that the perceived impact of potential obstacles to forecast use (accuracy, reliability of the source, etc.) was similar between short and long-term forecasts. In contrast, depending on the type of decision to be made, farmers in the study rated the usefulness of the different forecasts differently (for some decisions short-term forecasts were rated higher and vice versa).

Research Questions

Building off these previous studies, our work uses survey data from local stakeholders involved in water management in Guanacaste, Costa Rica to explore and compare potential personal and social factors related to the use of rainfall forecasts of several durations. In order to explore the perceptions and personal factors behind forecast use in the study area, we used the framework outlined in Figure 3.1 which is based on the literature mentioned above as well as previous work in the study area (Babcock et al. 2016):

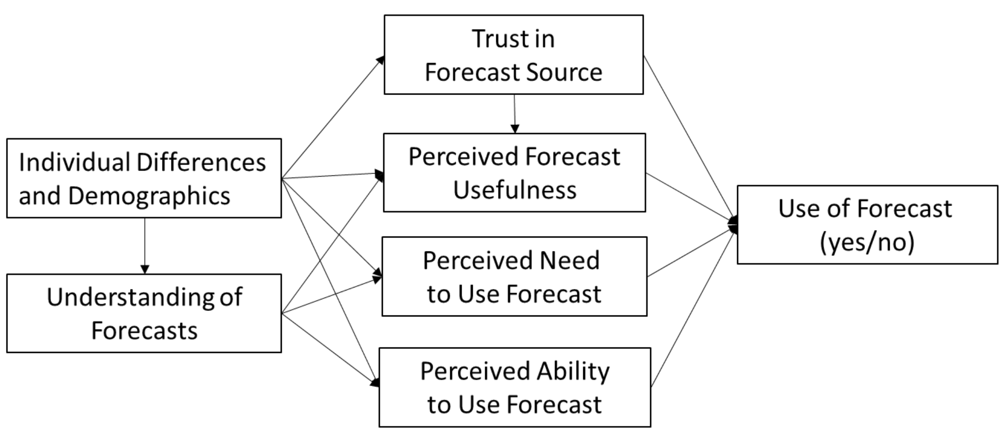

Figure 3.1 *Guiding framework for describing determinants of forecast use.*

The framework shown in Figure 3.1 can be mapped to something like the TPB framework as follows: Understanding, Trust, Forecast Usefulness and the Need factors contribute to a positive or negative attitude or feeling of social pressure toward the use of the forecast or ("Do I want to use the forecast"), while the Ability factor maps to the perceived control involved in using the forecast ("Can I use the forecast"). A more detailed discussion of the variables of interest that are incorporated into this framework can be found in section 2.4.

Our main research questions are as follows:

1. What are the relationships between the perceptions and personal factors that may influence the use of rainfall forecasts?
2. In the context of the study area, what are the relationships between the use of rainfall forecast and the 6 groups of factors outlined in Figure 3.1?
3. How do these relationships differ when considering rainfall forecasts of different time-scales (4-day, 3-month, 12-month)?

3.2 Methods

Study Area

This study is part of the FuturAgua Project in Guanacaste, Costa Rica, a multidisciplinary, multinational research effort supported by the G8 Belmont Forum to study climate change and freshwater security in developing nations (see: futuragua.ca/ubc/home/). Guanacaste is a seasonally dry tropical province, located between the central mountain range of Costa Rica and the Pacific Ocean. Historically, economic and cultural activity in Guanacaste centered on cattle ranching. Domestic/municipal growth, agricultural, hydro-electric power production, tourism developments, and environmental protection interests all place increasing demands on freshwater resources (Ramírez-Cover 2008). There has been a recent history of inter-stakeholder group conflict over water issues due in part to underrepresentation of local stakeholders in decision making and the lack of credible or available scientific measures of water quality and quantity (Kuzdas 2012 and van Eeghan 2011). Also, climate change forecasts and models, such as those included in the Fourth and Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) predict changes to the annual cycle of precipitation and increased temperatures, which may further stress the water systems in the region (Rauscher et al. 2008; Rauscher et al. 2011; Karmalkar et al. 2011; Ryu and Haehoe 2014; Neelin et al. 2006; Steinhoff et al. 2014).

Formal weather and climate forecasts for the region are provided to the public by the National Meteorological Institute (Spanish abbreviation: IMN), to various government agencies by both the IMN and the Costa Rican Electricity Institute (ICE), and are created for their own use by large farm operations with trained staff. The IMN provides daily and weekly forecasts through its website (IMN 2016). The IMN also provides for free on the website monthly climate reports that detail past precipitation and temperature and predict regional rainfall 3 months ahead. In contrast, ICE and the large farms do not share their information as publically. Many organizations and agencies also have access to NOAA forecast information. Some local stakeholders also use advice from friends and family and traditional methods of weather and climate forecasting. Previous mental models-based research conducted in the study area (Babcock et al. 2016) found that different stakeholder groups had different perceptions of the formal forecasts made by the IMN: stakeholders from large farms, hydroelectric plants, and government agencies all indicated a higher rate of use and understanding of such forecasts than those from small farms, tourist-oriented businesses, local water committees (ASADAs) and the public.

Survey Design

In order to collect information on forecast use and other variables of interest, we designed a structured survey that was given to stakeholders in the study region. The survey was designed in

English, translated into Spanish by the lead author, and pre-tested and edited for language by five native Spanish speakers (two PhD students at Carnegie Mellon University, two FuturAgua project members, and a member of a local advisory group located in Nicoya, Guanacaste). A paper version of the survey was developed in addition to an electronic one in order to accommodate participants without computer or internet access. Both versions of the survey were designed to meet Carnegie Mellon University Institutional Review Board guidelines, and both were identical in content with the exception that the electronic version included a progress bar and a "thank you" section at the end.

Recruitment and Participants

Participants were recruited through a variety of strategies including emailing potential participants identified on lists provided publicly or by NGO and government contacts, visiting country government offices, and visiting local meetings of rural water committees (Asociaciones Administradoras de Acueductos Rurales or ASADAs). All paper and electronic surveys were completed in Spanish, and participants were not compensated. All paper surveys were completed August-October 2015. All electronic surveys were completed between August-November 2015. It should be noted that while most often this time of year would have been part of the wet season in Guanacaste, in 2015 this period was very dry and the government had declared a drought emergency which may have affected participants' responses.

In total, the survey was provided to approximately 240 potential participants across Guanacaste province. A total of 87 survey participants completed the survey with the breakdown by stakeholder group as follows: ASADA representatives (17), representatives from the Ministry of Aqueducts (AyA - 26), Ministry of Agriculture and Livestock (MAG - 16), and Ministry of the

Environment (MINAE - 6), hydroelectric plant managers (2), large farmers (>500 hectares) (6), tourism oriented businesses (5), environmental NGOs (3), and members of the public (6). Participants that were employees of the Ministry of Aqueducts and Sewerage (Instituto Costarricense de *Acueductos y Alcantarillados or* AyA) or volunteer members of local water committees (ASADAs) were designated as Providers based on their role in the management of water resources (43 in total). All other participants were designated as Non-Providers (44) as these participants do not have legal responsibility to provide water to others. As self-reported, only 26% of the participants were female. This is low compared to the overall population, but within the range of female representation in groups like ASADAs, government agencies, and large farms. 25% of participants were between 18-34 years old, 37% were 35-49, and 33% were 50-65. 58% had at least an Associate's Degree level of education, 61% had children, and 17% had grandchildren. Approximately 30% of the participants had less than 5 years of work experience and 43% had 10 or more years of experience. Almost 80% of the participants had lived in their current location for 10 or more years. At least 2 participants came from each of the 11 *cantones* (counties). Considering the proportional population of each *cantón*, the *cantones* of Liberia, Santa Cruz, Cañas and Abangares are underrepresented and the *cantón* of Hojancha is over represented in our sample.

Variables

The survey had 7 sections: (a) general use of forecasts and sources of information, (b) understanding of example forecasts, (c) perceptions of example forecast accuracy, usefulness, and use, (d) levels of trust in forecast providers, (e) perceived need to use forecasts, (f) perceived ability to use forecasts, and (g) individual difference measures and demographics (see Appendix D for the complete English-version of the survey protocol):

(a) general use of forecasts

- *Use of Forecasts.* Participants were asked to indicate ("check all that apply") which of the following forecast types they used on a regular basis: weekly rainfall (4-day), seasonal rainfall (3-month), yearly rainfall (12-month), multi-year rainfall, groundwater level, traditional, river level and flow, reservoir level, economic, and El Niño. They were also asked if they used any additional types of forecasts.

(b) understanding of example forecasts

- As part of the survey, participants were shown three separate rainfall forecasts, a 4-day forecast, a 3-month average forecast, and a 12-month monthly average forecast. Each of these example forecasts were real forecasts produced by either the IMN or ICE. The 4-day forecast was for a period in August 2015, the 3-month forecast covered the period from July-September 2015, and the 12-month forecast covered a period from July 2014 to June 2015. Forecast images were modified to remove any reference to the source and for clarity, and the 12-month forecast was additionally modified to remove reference to specific geographic locations.
- Participants were given a total of 9 multiple choice questions (3 for each of the 3 forecasts) that tested their ability to read the example forecasts. For example, for the 3-month forecast the following questions were asked:
    1) According to this forecast, what will be the maximum amount of rain that Guanacaste will receive in the next 3 months?

2) According to this forecast, how many regions will receive less than the historic mean amount of rain in the next 3 months?

3) According to this forecast, which region will have the most negative percent difference from the historic rainfall mean in the next 3 months?

Each participant's *understanding* was calculated as the percentage of these 9 questions that they answered correctly.

(c) perceptions of example forecast accuracy, usefulness, and use

- *Example Forecast Accuracy.* For each example forecast, the participants indicated "what level of accuracy they would assign to that type of forecast" on a scale from 1 (not accurate at all) to 5 (perfectly accurate). There was also an "I don't know" option available.
- *Example Forecast Usefulness.* For each example forecast, the participants indicated whether they thought that type of forecast "seemed useful for managing water resources" on a scale from 1 (not useful at all) to 5 (very useful). There was also an "I don't know" option available.
- *Example Forecast Use Intent.* For each example forecast, the participants indicated whether they "would use this type of forecast to manage water resources" on a scale from 1 (never) to 5 (always). There was also an "I don't know" option available.

(d) levels of trust in forecast providers

- Participants indicated their *trust* in different forecast producers (government agencies, universities, private businesses, people that use traditional methods, friends and family) by rating their agreement (1 = very much disagree, 5 = very much agree) with the statement: "I trust ______." There was also an "I don't know" option available.

(e) perceived need to use forecasts

- Participants indicated how strong a *mandate* they had to use forecasts by rating their agreement (1 = very much disagree, 5 = very much agree) with the following statement: "I need to use forecast information for my work."
- Next, participants indicated to what extent they *consulted with others* by rating their agreement (1 = very much disagree, 5 = very much agree) with the following statement: "I consult with other people in my community or workplace when I take actions to manage water resources."
- Participants indicated their level of *responsibility* by rating their agreement (1 = very much disagree, 5 = very much agree) with the following statement: "I have the responsibility to manage water resources."
- Finally, participants indicated how *secure* they felt their water resources were over different time periods by rating their agreement (1 = very much disagree, 5 = very much agree) with the following statements: "There is enough water every time I need it to satisfy my needs," "There will be enough water every time I need it to satisfy my needs in the next year," and "There will be enough water every time I need it to satisfy my needs in the 5 years." Participants also rated their agreement with the following statement: "Knowing that there will be enough water to satisfy my needs make me feel safe."

(f) perceived ability to use forecasts

- Participants indicated their perceived *access* to forecasts by rating their agreement (1 = very much disagree, 5 = very much agree) with the following statements: "I know where to get forecast information" and "I can get forecast information when I need to."
- Participants indicated to what extent they had the necessary *economic, organizational, and information resources* to manage water resources by rating their agreement (1 = very much disagree, 5 = very much agree) with the following statements: "I have available the _____ (economic/organizational/information) resources that I need to manage water resources."

(g) individual difference measures

- *Forecast Sources.* Participants were asked to indicate ("check all that apply") which of the following sources of information they used: radio, TV, official reports, newspaper, meetings/workshops, internet, and family and friends. They were also asked if they used any additional sources of information. From this, a total count was made of how many information sources were used by each participant.
- *Resistance to Change*: Participants indicated their agreement (1 = very much disagree, 5 = very much agree) with the 17 questions of the Spanish language Resistance to Change Scale developed by Arciniega and Gonzalez (2009) from the work of Oreg (2003). An overall RTC score was calculated (alpha = .78) by taking the mean of these questions in accordance with Arciniega and Gonzalez (2009).

- *Religiosity:* Previous research in the study area (Babcock 2016) found some evidence that for some stakeholders their religious beliefs were incorporated into their perceptions of forecast. Participants in the current study indicated their agreement (1 = very much disagree, 5 = very much agree) with the following statement: "My religious beliefs are the core that guides my life."

Preliminary Data Analysis and Analytic Strategy

There were two parts to our analytic strategy: (1) exploratory factor analysis to help look for and understand latent concepts that underlie some of the independent variables, and (2) logistic regression to explore the relationship between use of different types of forecasts and the different variables mentioned above.

Exploratory factor analyses (EFAs) were conducted using a primary components extraction method with a varimax rotation where a unique EFA was performed on each group of the independent variables b – g mentioned above (in group c the Example Forecast Use Intent variable was not used in the factor analysis). Following from Demuth et al. 2011 and Garson 2013, we retained factors when the following conditions were met: 1) the factor must explain at least 10% of the variance, 2) each variable must have a value of at least 0.4 to load onto the factor, and 3) the variables that load onto a specific factor must have a Cronbach's alpha of at least 0.6. Factor scores from factors that met these conditions were used in the subsequent logistic regression analysis. Independent variables in our data set that were highly skewed including the responses to some of the demographic variables (gender, kids, and grandkids) were not used in subsequent analyses. For our analyses, the ordinal variables were treated as continuous. As much of our analysis is exploratory, we use significance levels of 10%, 5%, and 1% as Demuth et al. do (Demuth et al. 2011).

The majority of the binary dependent forecast use variables (from group a above) were also skewed which could bias the results of the logistic regression, and thus we decided to use only the responses to the 4-Day (yes = 37, no = 50), 3-Month (yes = 34, no = 53) and 12-Month (yes = 38, no = 49) forecast use questions, which showed less skew. Individual logistic regressions were run for each of the independent variable groups b – g and the results are shown in Table 3.2 in the next section. Groups c and g were each split into two analyses (Models 2 and 3, Model 7 and 8) as shown in Table 3.2.

3.3 Results

Exploratory Factor Analysis

Table 3.1 shows that the factor analysis of the trust variables resulted in two factors that met our criteria as described in the previous section. This result suggests that trusting an informal source does not necessarily mean that the participant does not trust a formal source as well.

Additional factor analysis of the other variables can be summarized as supporting the premise that several of our question sets (about access, resources, and perceived security) can be appropriately reduced to a smaller number of latent variables (additional results tables can be found in Appendix E). Factor analysis of the accuracy, usefulness, and intent to use variables for the three example forecasts results in the 3-month and 12-month forecasts loading onto one factor and the 4-day forecasts loading onto a second factor.

Table 3.1 *Results of factor analysis on the trust participants have in forecast producers. Factor loadings shown for each variable (N = 87).*

We would like to know how much you trust the people and institutions that make forecasts. Please indicate your agreement with the following statements.	Factors	
	T1	**T2**
Factor T1: Trust in traditional/informal forecasts		
I trust people that use traditional methods.	0.83	
I trust my friends and family.	0.85	
Factor T2: Trust in scientific/formal forecasts		
I trust government agencies.		0.52
I trust universities.		0.84
I trust private businesses.		0.54
% of total variance explained	31%	25%
Cronbach's alpha	0.82	0.65

Logistic Regression Analysis

Table 3.2 shows the results of the logistic regressions for each model and for each dependent variable (indicated regular use of 4-Day, 3-Month, or 12-month rainfall forecasts). Descriptive statistics for the independent variables used in each regression can be found in Appendix E. These results indicate that a higher understanding of forecasts was associated with a greater probability of using 4-Day and 3-Month forecasts. A higher level of trust in formal sources was associated with a greater probability of using 3-Month forecasts, while a higher level of trust in informal sources was associated with a lower probability of using such forecasts. In contrast, a greater sense of being mandated to use forecasts, a lower feeling of water security, and the use of a greater number of information sources were all associated with a greater probability of the 12-month forecasts.

Table 3.2 Results of logistic regressions (* < 0.10, ** < 0.05, *** < 0.01)

	Dependent variable: Use of Rainfall Forecast (1/0)											
	4-Day				3-Month				12-Month			
Models and Independent Variables	***B***	**SE**	**z**	**p**	***B***	**SE**	**z**	**p**	***B***	**SE**	**z**	**p**
Model 1: Understanding	2.66	1.21	2.20	0.03**	2.35	1.20	1.96	0.05*	1.21	1.11	1.09	0.27
Model 2: Perceived usefulness ST												
Short-term forecast (Scores from factor STU1)	0.37	0.29	1.29	0.20	-0.17	0.28	-0.60	0.55	-0.21	0.28	-0.74	0.46
Model 3: Perceived usefulness LT												
Long-term forecast (Scores from factor LTU1)	-0.15	0.31	-0.50	0.62	-0.09	0.31	-0.29	0.77	-0.00	0.31	-0.01	0.99
Model 4: Perceived need												
Mandated to use	0.00	0.32	-0.01	0.99	0.48	0.35	1.38	0.17	0.59	0.36	1.63	0.10
Consult with others	0.12	0.30	0.41	0.68	-0.02	0.30	-0.08	0.94	0.04	0.34	0.13	0.90
Responsible for managing water resources	0.28	0.36	0.79	0.43	-0.07	0.35	-0.19	0.85	0.42	0.41	1.02	0.31
Feeling of water security (Scores from factor S1)	-0.21	0.31	-0.69	0.49	0.04	0.31	0.13	0.90	-0.70	0.36	-1.96	0.05*
Model 5: Perceived ability												
Access to forecasts (Scores from factor A1)	0.02	0.26	0.09	0.93	0.10	0.26	0.38	0.70	0.02	0.25	0.10	0.92
Availability of resources (Scores from factor R1)	0.38	0.27	1.41	0.16	0.02	0.26	0.09	0.93	-0.12	0.26	-0.45	0.65
Model 6: Trust												
Trust in informal forecasts (Scores from factor T1)	-0.15	0.26	-0.59	0.56	-1.06	0.33	-3.19	0.00***	-0.43	0.27	-1.60	0.11
Trust in formal forecasts (Scores from factor T2)	0.00	0.25	0.00	1.00	0.50	0.31	1.63	0.10	0.20	0.25	0.80	0.42
Model 7: Individual differences												
Resistance to change	-0.22	0.42	-0.53	0.60	-0.71	0.44	-1.60	0.11	-0.54	0.44	-1.22	0.22
Religiosity	0.30	0.32	0.93	0.35	0.10	0.32	0.31	0.76	-0.28	0.35	-0.80	0.42
Log(Income)	0.08	0.38	0.22	0.83	0.36	0.40	0.91	0.36	-0.11	0.40	-0.28	0.78
Information sources (count)	0.22	0.22	1.02	0.31	0.13	0.22	0.59	0.55	0.55	0.25	2.23	0.03**
Model 8: Demographics												
Graduated college	0.31	0.54	0.57	0.57	0.48	0.53	0.91	0.36	0.81	0.53	1.52	0.13
Government agency representative	-0.75	0.48	-1.58	0.12	0.06	0.48	0.13	0.90	0.17	0.49	0.34	0.73
Provider	-0.42	0.51	-0.83	0.41	-0.18	0.51	-0.35	0.72	-0.66	0.51	-1.31	0.19

Table 3.3 shows the results of Chi-squared independence tests comparing the sources of information to the reported use of the three forecasts. Radio, newspaper, and internet use was associated with the use of 4-day weather forecasts. Report use was associated with the use of 3-month and 12-month forecasts and obtaining information through meetings was associated with the use of 12-month forecasts.

Table 3.3 *Results of chi-square independence tests (* < 0.10, ** < 0.05, *** < 0.01)*

	Use of Rainfall Forecast (1/0)								
	4-Day			3-Month			12-Month		
Source	X^2	**df**	**p-value**	X^2	**df**	**p-value**	X^2	**df**	**p-value**
Radio	4.908	1	0.027**	1.878	1	0.171	0.885	1	0.347
TV	0.224	1	0.636	0.453	1	0.501	0.027	1	0.869
Report	0.892	1	0.345	6.376	1	0.012**	7.433	1	0.006***
Newspaper	6.912	1	0.009***	0.040	1	0.842	1.595	1	0.207
Meeting	0.334	1	0.563	0.136	1	0.712	10.410	1	0.001***
Internet	5.584	1	0.018**	0.000	1	1.000	0.248	1	0.618
Family	0.023	1	0.880	1.966	1	0.161	0.441	1	0.507

3.4. Discussion and Conclusions

Differences in determinants of use of forecasts of different lengths

Our results suggest variation in what factors are associated with affect the use of rainfall forecasts of different lengths. Our exploratory factor analysis results do support that the participants viewed the usefulness and accuracy of both 3-Month and 12-Month forecasts as similar to each other but different from how they viewed 4-Day forecasts. This result echoes previous studies that have shown that there are differences in how short and long-term forecasts are thought of and incorporated into decision making (Hu et al. 2006). Our results suggest that only understanding of the forecast and getting information from radio, newspaper, and the internet are associated with the use of 4-day weather forecasts. The possibility that week-scale actions and uses of such forecasts may not require as much attention or resources also may explain why only the level of understanding of forecasts and mass media sources like radio and newspapers appeared to be associated with their use.

Understanding was also associated with the use of 3-month forecasts, though not with the use of 12-month forecasts. In fact, except for using reports as a climate information source, our results also suggest that the factors associated with the use of 3-month and 12-month forecasts are not the same, which may be surprising as they contain similar information. While trust in informal sources was associated with a lower chance of using 3-month forecasts (which we discuss in further detail below), that higher probability of use of 12-month forecasts was suggested to be associated with a greater perception of water scarcity, the use of a greater number of forecast information sources overall, and specifically the use of meetings as a source of information. These results suggest that use of 12-month forecasts is more spurred by a sense of needing to use the forecasts in comparison to 4-Day and 3-Month forecasts. The fact that obtaining information from meetings was associated with the use of 12-month forecasts, but consulting with others was not necessarily, may additionally indicate that use of such forecasts is perceived to be more pushed upon the user (the coefficient on the mandate variable, while not statistically significant to the 0.10 level, does seem to support this also). There is also perhaps a signal that there is a more intrinsic reason to use 3-Month forecasts than yearly forecasts (i.e. matches work cycles better) but such use faces barriers due to lack of understanding or a high level of trust in other methods of forecasting.

Trust and 3-Month Forecasts

An interesting result from the factor analysis of the Trust variables is that there appear to be two independent underlying factors: a trust in formal (government, university, and private company) sources of forecasts and a trust in informal (traditional and family) sources. This is opposed to the formal and informal sources representing two extremes of a single continuum, where trust in formal would indicate a lack a trust in informal and vice versa. This result might suggest that efforts to increase trust in formal sources (and thereby perhaps increasing the use of forecasts from such sources) need not necessarily also involve decreasing trust in informal sources. The results of our regression analysis though, indicate that the picture is more complex for 3-Month forecasts, where one of our most significant findings is that higher trust in informal sources is associated with a lower probability of using 3-Month forecasts. This is also supported by the result that obtaining information from family members (an informal source) is associated with a lower level of 3-month forecast use. Since it may be difficult to lower trust in informal sources, these results may underscore the need to increase trust in formal sources. Thus, it may be important to explore further the reasons how trust in different sources is built and/or maintained. For example, other studies have pointed out the importance of how credible forecast providers and users are in each other's eyes in relation to the use of forecasts and how important participatory development of forecasts is to this credibility (Patt 2006). In the Guanacaste case, the formal forecasts are not created in a participatory manner but rather handed down and out by the IMN. Informal forecasts in the region on the other hand may be more participatory as they consist of conversations with the user's friends and family or their local go-to person for traditional knowledge. Perhaps if formal forecasts were made in a more participatory manner the level of trust that some stakeholders have in formal sources could be increased to a point where it “counteracts” the continuing trust in informal methods. Another potential option is to further explore how trust in informal sources specifically in terms of forecasts could be mitigated without damaging those informal relationships. Differentiating the trust in or credibility of formal versus informal forecasts may also be useful in other contexts outside of Guanacaste.

Limitations and Conclusion

As described in our methods section, our ability to extrapolate these results to a larger population may be limited due to our sample size and demographics. Also, as a controlled experiment was not performed our results should not be interpreted to indicate a causal argument. Another factor that could affect our results is whether participants had the same understanding of the different types of forecasts when answering the general use questions (as these were presented before the examples).

Taken together, our results suggest that the stakeholder’s attitude toward the forecast (or forecast provider) plays a larger part in determining whether any of the forecasts are used than a notion of perceived control. Social norms seem to play a part in the decision to use 12-month forecasts, and may play an underlying part in decisions about 3-Month forecast, though this requires further study.

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IV. INVESTIGATING HOW ORGANIZATIONS AND INDIVIDUALS DECIDE TO ENGAGE WITH CLIMATE INFORMATION BOUNDARY CHAINS

In both our Guanacaste-related research and in the literature, we found the recurring theme of the importance of trust between different groups involved in the communication of climate and adaptation information. This is especially true when the process involves groups that are skeptical of established climate science. One Montana's Resilient Montana program is an example of an attempt to form a trusted climate adaptation information network between farmers, ranchers, local water managers and climate and adaptation scientists with the goals of increasing participation in related discussions and increasing the use of resilient water management strategies. One Montana seeks to accomplish this by bringing the different groups together for workshops and dialogues where the emphasis has been on climate impacts and how to deal with them (as opposed to the causes of climate change). In this effort, One Montana acts as a boundary organization in that it connects different stakeholder groups (and is made up of individuals from those groups), assists with translation between disciplines and societal divides, and helps to generate trust. One Montana cites the fact that they have been invited back to certain groups to continue the resiliency conversation as evidence of the success of their chosen methodology. Studying how the Resilient Montana project came to be and currently works allows us to learn how trusted networks are formed and whether they are successful at increasing stakeholder intent to seek out, share, and act upon the information being communicated. Due mostly to the timing of the One Montana workshops, this study mainly focuses on interactions with ranchers (who are a group that on average is assumed to be skeptical of climate science according to One Montana).

4.1 Introduction

Polarization as a challenge to climate communications

Recent research in successful water resources and climate adaptation management has focused on two overarching trends: integrated water resources management (IWRM), in which multiple stakeholders and goals are included in the decision making process, and adaptive management, in which iterative learning about the system takes place (Pahl-Wostl et al. 2007, Pahl-Wostl et al. 2008, Engle et al. 2011). The nature of the interaction between different stakeholder groups has been shown to be important for both styles of management (Pahl-Wostl et al. 2008). Regions in which important stakeholder groups understand, communicate with, and trust each other have been found to be better able to take advantage of such strategies and help ensure equitable and efficient use of water resources. In the Western United States, the relationship between urban and rural groups is especially important for legal ("first in time" water rights are held by rural agriculturalists), historical (there is an ongoing shift from predominately rural populations to majority urban ones), cultural (rural life is valued), and physical reasons (watersheds currently or projected to be under stress contain both rural and urban areas). Under changing climate conditions and evolving socio-economic relationships it is ever more important that strategies for ensuring successful communication and coordination between groups are studied, promoted, and implemented. Without successful communication and coordination, non-traditional management strategies and types of information that are designed for facing a more variable environment may be underused.

It is therefore problematic that, at the very time that additional communication and cooperation is required for successful resource management, social divisions have exacerbated the barriers to such communication. In the United States, the ever-growing partisan divide in both the media and political classes (Prior 2013, Fiorina and Abrams 2008), and the potential for deepening polarization within the public (Druckman et al. 2013), shuts down lines of communication and exacerbates the distance or lack of trust between stakeholder groups. As there is more polarization, political identity has interfered more with open and honest environmental and climate debates (Dunlap et al. 2016, Bliuc et al. 2015). There is a currently a confluence of political polarization with the growing distinctions between rural and urban areas and the ongoing difficulty of science communication when dealing with complex and uncertain subjects such as climate adaptation. This can result in needed conversations about climate and resource management not occurring and further pushing divided groups away from each other. Without successful communication between stakeholder groups, the possibility increases that less informed decision making will occur, that the needs of all parts of the water sector will not be met, and that confrontation or conflict over water resources will occur.

Boundary chains to close the gap

Boundary organizations connect disparate stakeholder groups, are typically made up of members from those groups, help translate and mediate between disciplines and across societal divides, and help other groups strengthen their ties to one another (Cash et al. 2006). Past research has shown the broad importance of boundary organizations in overcoming barriers to the use of scientific climate and environmental information by local stakeholders (Kirchhoff et al. 2013, Feldman and Ingram 2009). By connecting and translating between groups, boundary organizations can help ensure information providers are more aware of user contexts and that users have more trust in the providers. This helps to ensure that science communication meets both Cash et al.'s "credible, salient, and legitimate" criteria and Lemos et al.'s broader framework of "fit, interplay, and interaction" for successful communication (Cash et al. 2003, Lemos et al. 2012). For example, agricultural extension programs have a long history in the United States and elsewhere of connecting local agriculturalists to agricultural scientists in a boundary organization-type manner (Cash 2001). Successful programs have allowed scientists access to field information that helps them to design more appropriate tools, and have increased the trust that agriculturalists have in the scientists' abilities and intentions. The support that functioning boundary organizations provide to the communication may be especially important in contexts in which the distances or divisions between the scientists and information users are exacerbated by and embedded within larger urban/rural or political divides.

An important strength of boundary organizations or boundary chains (multiple connected boundary organizations – see Lemos et al. 2014) is that they "open a dialogue…while minimizing the politicization of science and the scientization of policy" and "help to bridge the different cultures of science production and use" (Kirchhoff et al. 2015). Kirchhoff et al. also note that, in addition to exploring how boundary organizations assist in these ways, the research has recently expanded to include examining the "structure and sustainability of boundary organizations themselves."

Looking at the structure of boundary chains, Lemos and her colleagues have distinguished three different arrangements of boundary chains that demonstrate different aspects of the work they do (Figure 4.1). "Key" arrangements are those where the one organization of interest helps connect different organizations to the overall network and "broadens the diversity of the users." "Linked" chain arrangements are those where the organization is part of a chain that connect across a divide (such as between scientist and local users or between geographic levels) and provides translation or customization services. Importantly, "linked" chains can provide both content and process translation (both what should be conveyed and how it should be conveyed). “Networked” arrangements help build boundary chain capacity by combining both “Key” and “Linked” arrangements and supporting connections between other groups (Lemos et al. 2014).

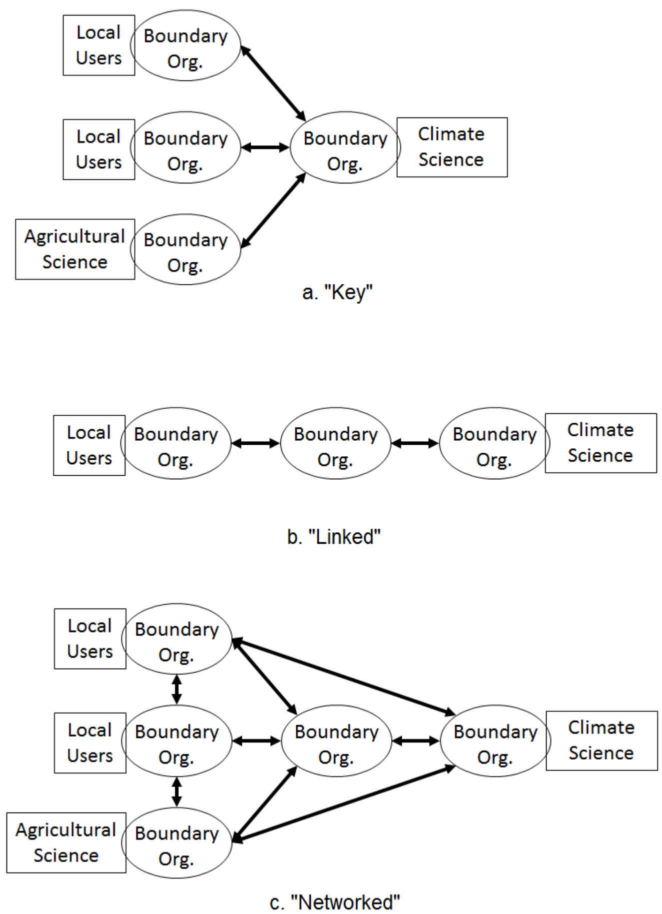


Figure 4.1 Three types of boundary chain arrangements: a. “Key” chains that connect different groups; b. “Linked" chains that translate across societal divides; c. "Networked" chains that help create or strengthen group ties. “Climate Science” and “Agricultural Science” are used as examples of different areas of expertise that boundary chains can connect. Adapted from Lemos et al. 2014.

According to Kirchhoff et al., successful boundary chains contain organizations that are *complementary to each other*, meaning that each organization shares some goals but brings different connections, views, and resources to the table, and *embedded with each other*, meaning that the actions of one part of the chain affect to some extent the decisions made by other parts (Kirchhoff et al. 2015). If constituent organizations don’t have complementariness, then the boundary chain is likely to not form in the first place, or, if there is a loss of complementariness, then the boundary chain may cease to exist. If there is no embeddedness, then the boundary chain may not effectively or efficiently take advantage of the connections within the chain.

One Montana's Resilient Montana Network

In this study, we focus on a boundary organization and its related network located in the state of Montana and dedicated to facilitating climate and water sector adaptation discussions between agriculturalists and scientists. Montana makes for an interesting case due to existing rural and urban divisions and existing and projected climatic changes that are expected to affect water resources in the state. Our focus boundary organization, One Montana (http://onemontana.org/), has historically aimed to bridge the gap between rural and urban Montanans through rural-urban student and agricultural exchanges and through facilitating landowner/hunter agreements. Recently, One Montana has been working on the Resilient Montana project that seeks to improve statewide climate and water systems adaptation by bringing together stakeholders (ranchers, farmers, climate/adaptation scientists and practitioners) to discuss climate impacts and adaptation strategies pertaining to water resource management. Table 4.1 summarizes some of the historical events, projects, and connections that One Montana has worked on related to agriculture and climate/water management.

Table 4.1: Summary of selected One Montana (OM) and related projects/events (based on interviews and www.onemontana.org)

Year	Project/Event Description	Participating Groups
2009	With support from the Packard Foundation to focus on rural/urban divides, OM is formed out of the Rural Landscape Institute. Precursors to Common Ground and Montana way projects ongoing.	OM, Packard Foundation
2012	Common Ground – convening land owners and sportsmen for discussions, hunter education (extension of work done under Rural Landscape Institute)	Landowners – Hunters
2014	Montana Way – interviewing large landowners about community engagement and management to inform new landowners (extension of work done under Rural Landscape Institute)	Established/traditional large landowners – New/non-traditional large landowners
2014	Meat Processing feasibility study	MT Dept. of Ag. – MT Stockgrowers – Universities – Ranchers
2014	OM starts Resilient Montana project, and with Union of Concerned Scientists puts on 2-day workshop on climate science communication with MSU extension, MCA scientists (1st day), mix of scientists and ag. stakeholders (2nd day)	UCS – MSU Extension – MCA scientists – trade organizations –ag. stakeholders
2014	MSU Extension creates Climate Science Team	MSU Extension
2015	OM assists MCA by setting up listening sessions with farmers (Oct) through trade organization contacts. Workshop includes panel presentations from scientists from MT and USDA.	MCA scientists – MSU Extension – MT Farmers Union – Farmers – MT Dept. of Ag.
2015	OM assists MCA by setting up listening sessions with ranchers (Dec) through trade organization contacts. Workshop includes panel presentations from scientists from MT and USDA.	MCA scientists – MSU Extension – MT Stockgrowers – Ranchers –USDA Climate Hub – Montana Climate Office (MCO)
2015	OM helps organize MSU Extension climate science conference.	MSU Extension – MT Stockgrowers – MT Farm Bureau – MT Wildlife Federation – MT Farmers Union
2016	OM researches and writes white paper on climate mitigation and adaptation for ranchers and farmers.	OM – MCA scientists
2016	OM assists in setting up discussions Association of Gallatin Agricultural Irrigators (AGAI) with the City of Bozeman about educational initiatives and water resource use in the Gallatin valley.	City of Bozeman – AGAI – Irrigator agriculturalists
2016	OM coordinates follow-up rancher resiliency workshops at Stockgrowers annual meeting and through MSU Extension. Panel presentations from MCA scientists, MCO, MSU extension, and USDA	MSU Extension – MT Stockgrowers – Ranchers –USDA Climate Hub – Montana Climate Office (MCO)

As Table 4.1 shows, much of One Montana's earlier work was focused on projects that involved creating and/or strengthening contacts with trade organizations, government programs, and individuals involved with ranching and farming. Previously established personal contacts with the Union of Concerned Scientists helped result in the 2014 workshop, through which One Montana brought together climate and agricultural scientists from the university system, trade organizations, and other agricultural leaders in the state. Since then One Montana has played a role in organizing and facilitating workshops and listening sessions aimed at continuing to have open discussions between ranchers, farmers, and climate and agriculture scientists from the Montana Climate Assessment (MCA), Montana Climate Office (MCO), and Montana State University (MSU) Extension. Figure 4.2 presents a simplified picture of the boundary network/chain in which One Montana plays a connecting role through their Resilient Montana project:

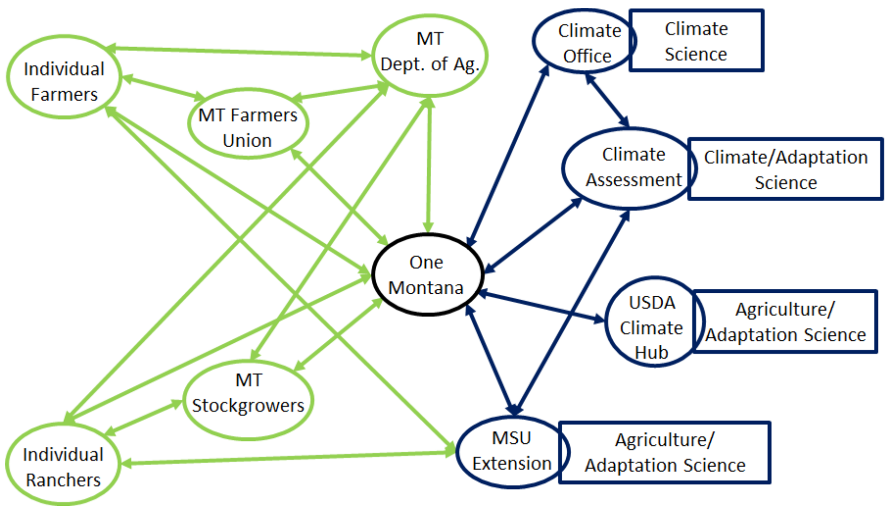
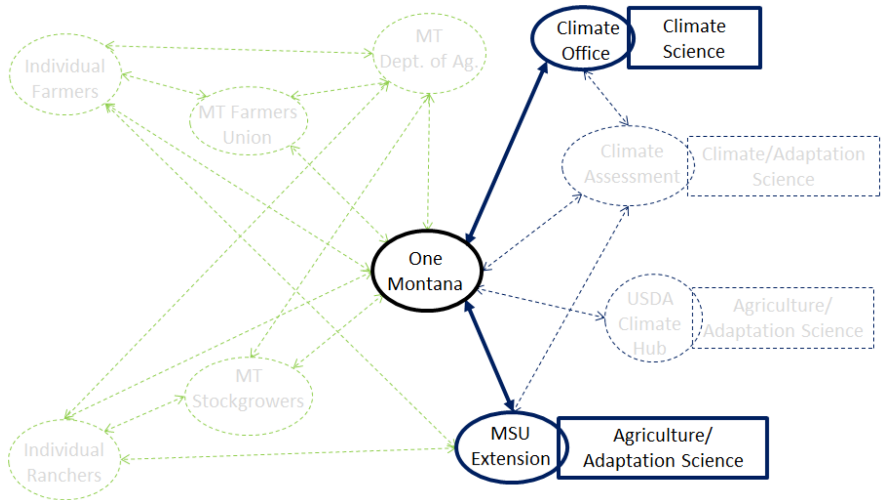
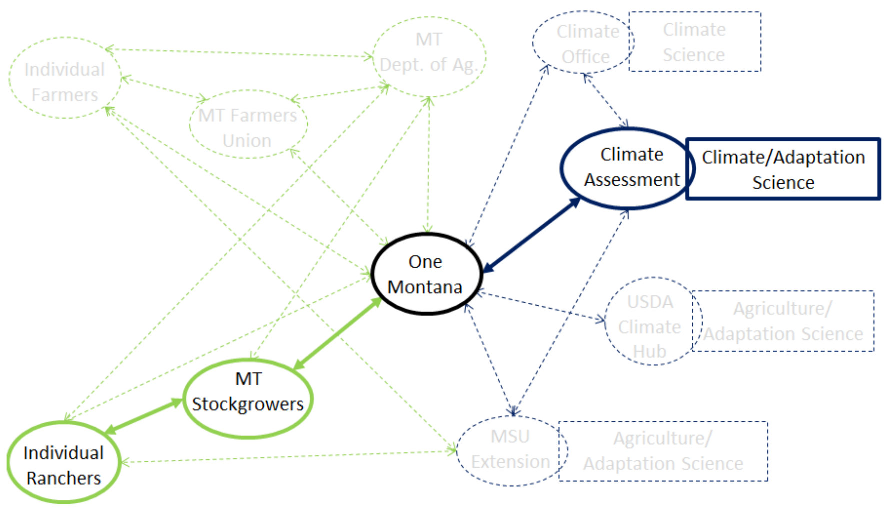


Figure 4.2: One Montana Boundary network chain (resiliency workshop projects). Green/lighter lines represent agricultural network connections. Blue/darker lines represent climate and agricultural science network connections.

This networked chain consists of multiple smaller chains of both the “key” and “linked” variety. Figure 4.3 shows an example of each type.



a. "Key"



b. "Linked"

Figure 4.3: Example sub-arrangements from the One Montana workshop-related network. In a. One Montana is the "key ring" that connects the Montana Climate Office with MSU Extension. In b. One Montana is part of a "linked" chain and helps translate between the science side of the divide and the agriculturalist side.

It should be noted, that while One Montana plays a pivotal role in connecting the scientist side of this network with the agriculture side, it also has played a role in connecting different "science" groups to each other (MCO to MSU Extension through workshop participation for example). Figure 4.4 shows another example of how One Montana operates in a "linked" chain in its work to connect AGAI (Association of Gallatin Agricultural Irrigators) and the City of Bozeman (another project under the Resilient Montana project).

Figure 4.4: OM Boundary linked chain (irrigator project)

One Montana points to its series of adaptation workshops as signs of the success of its Resilient Montana project in that a) open conversations have taken place among individuals from across the science/agricultural divide in the same room, and b) the organization has been invited back to coordinate additional workshops. One important aspect of these workshops is that individual ranchers and farmers attend who may or may not be affiliated with larger organizations. Whether such individuals "buy-in" to the boundary chain (be willing to come back to similar workshops or otherwise seek contact with organizations represented at the workshop) may depend on the perception of being affected by changing climate and weather conditions (O'Conner 2005), whether they have had prior contact with the organizations (Ingold 2017), and whether they found the information in the workshop informative (Cash et al. 2003, Lemos et al. 2012). The perception that they are threatened by changing climate or weather conditions may have also led to prior contact with experts. Feeling threatened and having prior contact may also affect participants' perception of how informative the workshops are. Figure 4.5 shows a simplified influence diagram representing the hypothesized relationships:

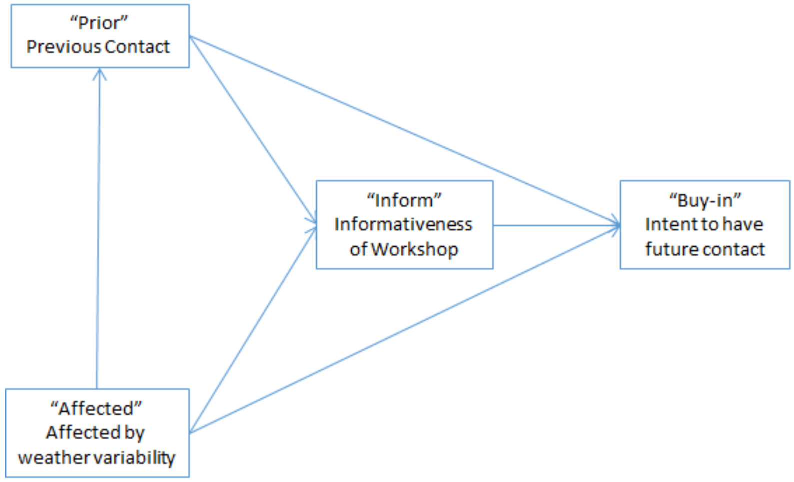


Figure 4.5: Hypothesized influence diagram showing determinants of "buy-in"

Research Questions

Although there is a clear history of connections made through One Montana's efforts, examining why organizations decided to engage with the workshops or other activities of the Resilient Montana boundary network may be helpful in further understanding how boundary chains form and are maintained. Additionally, exploring what individuals think about the workshop and what prompts them to return for future discussions may be helpful in understanding how individuals become connected to a boundary chain. Having One Montana as the focus for this investigation of boundary chain engagement is also somewhat unique in that overall One Montana is not a producer of climate and water science products itself, unlike the NOAA RISA program or historic extension agencies (the interesting exception to this being the recent white paper on mitigation and adaptation – see Table 4.1).

In this study, we sought to answer the following research questions:

1. What role does One Montana play in the Resilient Montana boundary network?
2. What prompts other organizations to engage with One Montana and its network?

3. What do members of organizations in the boundary network perceive as successful and unsuccessful ways of communicating climate-related information between scientists and ranchers?

4. What prompts individual ranchers to seek out further connection or "buy-in" to the climate adaptation-related boundary chains One Montana is a part of?

Consistent with a decision science approach (Wong-Parodi et al. 2016), we used a mix of qualitative and quantitative methods to answer these questions:

Interviews: To answer questions 1, 2, and 3 we conducted semi-structured one-on-one interviews with individual members of One Montana and the Resilient Montana network. The breadth of the interviews covered views on One Montana's purpose, strategies, and successes, reasons why and manner in which organizations engage with One Montana, participant views on Montana's climate and its impact on ranchers, and views on what makes for successful communication between scientists and ranchers. The overall purpose of these questions was to get an understanding from the existing network about the reasons to engage in it and how to communicate about climate-related issues in a way that supports engagement.

Surveys: To answer question 4, we conducted surveys at two of the resiliency workshops that One Montana organized for ranchers. The purpose of the surveys was to gather data that could be used to help determine the drivers of future participation in workshops or other contact with the boundary network on the part of individual ranchers, and was organized around the influence diagram shown in Figure 4.5.

4.2 Interviews with members of One Montana's Network

Methods

Recruitment: We recruited 21 participants with the help of One Montana. One Montana introduced the first author to key informants who have current or past membership or affiliation with their organization, and then helped set up interviews with these stakeholders. The interviews were conducted October-December 2016, and took place in person at a location convenient for the participant (one interview was conducted remotely). The interviews lasted approximately 30-60 minutes and were audio recorded for later transcription. Carnegie Mellon University's Institutional Review Board approved the research protocol. Verbal informed consent was obtained from all participants, and they were not compensated for their time.

Participants: Table 4.2 shows the breakdown of participants by their main group affiliation:

Table 4.2 Interview participant affiliations

Primary Participant Focus	Specific Organization	n
One Montana	One Montana Staff (current)	3
	One Montana Staff (ex-staff)	2
	One Montana board member	2
Climate, Adaptation, and Agricultural Science	Montana Climate Assessment (MCA)	4
	MSU Extension (MSU Ex)	2
	Montana Climate Office (MCO)	1
Agriculture Practice	Trade organizations	2
	Montana Department of Agriculture	2
	Agricultural Irrigators	3
Total		**21**

One third of the participants were or had been part of One Montana itself, one third were primarily science based, and one third were primarily agriculturally based. In addition to the 7 from the Agriculture group, 2 members of One Montana and 1 member of the Science group all had familial or personal experience with ranching or farming. Seven participants were female, and all participants had at least a Bachelor's degree. The median age of participants was 54, and most (17) had lived in Montana for over 10 years. When asked about their political affiliation, most identified as progressive leaning (47.6%), followed by conservative leaning (28.6%) and neutral (23.8%).

Interview Protocol: The interviews consisted of both open-ended and closed questions divided into three main sections (see Appendix F for the full protocol).

First, we asked participants about their understanding of, opinion of, and experiences with One Montana. This consisted of open-ended questions such as, "Can you please tell me about One Montana/Resilient Montana?", "In your opinion, what are the goals of One Montana?", and, "Can you please describe what your interaction with One Montana is like"? We also asked about the participant's timeline of interaction with One Montana, and about which individuals within the network the participant interacted with and at what frequency. For this network part, we first asked the open question, "Who do you work with related to One Montana"? We then walked through a list of network members and asked the participant about the nature and frequency of interaction with each member. The list of network members was provided to us by One Montana and comprised most of the interview participants (about 20 people). Due to time constraints for some of the interviews, this information was not collected for every participant.

In the second part of the interview, we asked additional open-ended questions focused on participant's beliefs about Montana's climate ("Please describe Montana's present climate?", "Has there been a change in climate and/or water resources in the last 1 to 2 decades?", "How do you expect climate or the state of water resources may change in the future?" We then asked, "Why is it important for ranchers to know about climate science?" and "How are they affected"? This section ended by asking participants, "What specific concepts do you think ranchers need to understand about climate science and its effects on water availability and why?" and "What specific actions do you think ranchers need to take to respond to changing climate"?

In the third section, we asked participants to, "Please describe experiences you have had with successful and unsuccessful communication of climate information to/with ranchers" and, "Can you please describe what leads to successful communication". For this last question, we asked participants to speak about successful strategies in terms of both the message and the process.

We also asked some basic demographic questions (age, educational/professional background, how long they had been in Montana, and political preferences).

Analytical Plan: We analyzed the interview transcripts in two ways. First, we reviewed the transcripts for any additional information regarding the network history (both between organizations and between individuals). Using such data we planned to conduct formal network analysis similar to that performed by Ingold (2017). This analysis would potentially have assisted in better understanding who were the important contacts within the network for connecting new organizations, and whether engagement in the network could be explained by the structure of the network. Due in part to the time constraints and open-ended nature of our interview process, we have a large amount of missing data on specific connections between individuals. As such, it is of limited use to perform more formal network analyses on the data we have. We therefore have instead constructed a description of the network using a qualitative approach as others have, in part, done (Rhoten 2003).

Second, we reviewed the transcripts and identified important main themes and sub-themes (Gibbs 2008). Many of the main themes were related to the questions we asked directly. As an example, under the main theme of "successful communication strategies" was the sub-theme "focus on ranching operations." The one main theme that was not explicitly asked about in our protocol but that came up to some extent in almost every interview was that of "societal divisions" Information under the theme of "reasons to engage with One Montana" was used to add detail to the overall network description. Whether a specific sub-theme was mentioned by each participant was noted (1 – yes, 0 – no) to allow for comparisons of the frequency of mention and between individuals and groups.

In the following results, we first present a description of the One Montana network and the reasons organizations engage with One Montana, and then present the themes related to participant views on what leads to successful communication of information with Montana ranchers.

Results

Interview participant views on One Montana's role and boundary chain network

As we interviewed both participants who worked at One Montana directly and those who work at outside organizations, we were able to get a picture of how the organization views itself and how others outside view it.

One-Montana Staff and Board Members

Internally, staff and board members were consistent in defining what One Montana's role was, what communication strategies the organization employed, and what the results of their work were, both successful and not. In order to, "bridge the rural/urban divide" as is their stated mission, these participants spoke about One Montana as a "trusted catalyst" whose main activity is connecting other groups together and facilitating discussion between them. Most One Montana participants defined success as getting groups to be willing to come back to further interactions with each other. For example, the fact that a trade organization that declined to host a resiliency workshop between ranchers and scientists in 2014 decided to do so in 2015, and decided to host a second one in 2016, was mentioned as the kind of successful interactions that

One Montana is interesting in helping generate. Interview participants mentioned that many of these connections were facilitated by having One Montana staff or board members who had ranching/farming backgrounds or who had been active in the related trade associations. Success was expressed by some as not necessarily meaning that the groups had to come back to One Montana, but rather that the connections created through a One Montana project, were sustained. As an example, one participant said,

> "*we take a lot of pride in for example if [] who works at the Climate Office suddenly has this list of ranchers that he is working closely with and we helped make those connections and we helped him become more confident and comfortable going out into rural ag country, rural Montana and interacting with farmers and ranchers"* **Participant "59"**

Some One Montana-based participants also used the term "safe space" to refer to the idea that they were interested in getting different groups together in a way that was honest and open, but not confrontational, allowing those groups to find some common ground. Those that used "safe space" also focused on One Montana's role in blunting the political acrimony that they thought had taken hold both nationally and locally and made it difficult to have necessary conversations over natural resources. Part of One Montana's ability to blunt political flair-ups may be due to its place in a boundary network. As One Montana is connected to groups on both sides of the political spectrum, it may be harder for an individual to summarily dismiss them as partisan and politically "unsafe" to talk to. Some participants also mentioned One Montana's role in setting the agenda at their events, and thus their ability to avoid, as one participant put it, "grenade throwers," who would outrage different political factions in the room. This may be a very important role as Kirchhoff et al. (2015) provide an example where a boundary chain exhibited good complementariness and embeddedness, but whose efforts were still derailed by political operatives/activists.

External Network Members

Outside participants who were knowledgeable about One Montana, also understood One Montana's overall mission to be "bridging the urban/rural divide." Most saw this as a noteworthy and needed goal. Societal divisions that need to be overcome was a theme brought up by almost all interview participants, even without direct prompting. When asked about their opinion of One Montana, most participants described One Montana as a trusted and neutral organization. Participants described several reasons for why their organization or group chose to engage with One Montana on climate and water related projects:

- **Access to other groups.** Participants from the climate and agricultural science groups mentioned that partnering with One Montana allowed for additional access to agricultural stakeholders and other science groups including both individuals and organizations. Irrigator participants stated that they partnered with One Montana in part because One Montana could set up introductory meetings with city officials.
- **Process and content translation.** Some participants mentioned that One Montana was helpful to them in not only setting up initial connections with other groups, but also in assisting with the process by which additional connections took place or in choosing what to focus on during these connections (workshops, meetings). For example, the irrigator participants mentioned that the timelines on which the city and farmers work are different (with city groups meeting more, moving faster, and taking a longer view than farmers) and that this can lead to miscommunication or to farmers feeling at a disadvantage. Through setting up meetings, providing email and phone reminders and other similar activities, irrigators said One Montana has helped them match the timeline on which the city is working.

- **Subsidization.** Similarly, several participants from the science groups, trade organizations, and irrigators mentioned that One Montana was helpful by directly subsidizing some of their work by taking the lead on logistical matters. In this manner, One Montana was not necessarily contributing something novel, but instead simply helping to reduce the costs associated with work that the organizations were already doing.
- **Funding.** Some participants mentioned One Montana had assisted their organizations by helping to find funding for various projects.
- **Past contact.** The above reasons all focus on what connecting to One Montana helps provide the outside organizations. In addition to their trusted reputation, having prior contact with One Montana was mentioned as a main reason for engagement specifically with them. For example, ranching-focused participants felt that having worked with One Montana on purely agricultural programs in the past allowed them to continue working with them on the climate-related workshops. This prior contact was important on an individual basis as well, as several study participants mentioned that their personal contact with individual One Montana staff on issues outside of One Montana projects had led them originally consider partnering with the organization.

The first two reasons mentioned (Access to other groups and Process and content translation) are very much roles that reflect boundary organization work and align with the connecting "key" chain (getting groups together who otherwise would not get together and/or making introductions) and translating "linked" chain (helping to set the agenda, choose the people, match processes between groups) arrangements exemplified in Figure 4.3. The subsidizer and funder roles that One Montana plays can perhaps be considered boundary functions in the sense that by freeing up resources for their partner organizations One Montana may be enabling them to spend more efforts connecting with each other (somewhat of the “networked” chain affect). Similarly, even if these functions are less boundary oriented, they do build additional trust in One Montana, which may strengthen the network as a whole.

Communication strategies

The most frequently mentioned measure of successful communication that participants brought up during the interviews was that the communication about climate continues – that ranchers come back to the table or future workshops, and there is continued engagement between ranchers and climate and adaptation scientists. Table 4.3 summarizes some of the most commonly mentioned themes from the interviews related to maintaining channels of communication between groups as well as why participants thought these strategies worked:

Table 4.3: Communication strategies and reasoning behind them mentioned by participants.

Communication Strategies	**Reasoning**
Content Related	
1. Emphasize climate adaptation/water management not mitigation.	- Impacts matter more to ranchers. - Less likely to trigger partisan identities. - Not seen as an attack on agriculture. - Not seen as first step to government regulation. - Starts with a lot of common ground.
2. Connect content to ranching operations/economy.	- Matters to ranchers - Ranchers know about this and can relate - Can frame adaptation as opportunity. - Shows audience that the information provider is aware (and cares) about their situation
Process Related	
1. Acknowledge rancher experience.	- Avoids ranchers feeling dismissed or talked-down to - Shows audience that the information provider is aware (and cares) about their situation
2. Increase two-way contact.	- Increases trust (intention, contact)

Content: Emphasize climate adaptation not mitigation (at least at first)

The content-related strategy mentioned by the most participants (17/21) was to focus on the topic of weather variability and the effects of climate change (changes in amounts and types of precipitation, temperature, and extreme events). Conversely, they opposed conversation focused on the causes of climate change and anthropogenic climate change mitigation. Although some participants did not mention or dismissed ever engaging the issue of mitigation, many mentioned taking advantage of conversations and connections which started with impacts and adaptation as a starting point in a conversation that could eventually include mitigation. As two participants stated:

> *"Telling a rancher that what he's doing is is (sic) ruining the climate does not really go well…it is a much better way to sort of have discussions about how weather patterns have changed… Which I think in turn then can help to evolve into a conversation about mitigation effects to the overall broader picture of, you know, carbon emissions and greenhouse gas emissions and how the greater beef industry can improve its footprint and invest in research and innovation and technology."* **Participant "77"**

> *"Where three years ago, they (trade associations), it was too scared to bring it before their members because they felt that it would be that they were all in a state of denial. Well, they were in a state of denial when you're talking about it (climate change) in a different language that wasn't their language. But it's like an organizing principle – you got to start from where they are and then you work off that."* **Participant "62"**

There were two main reasons given by participants as to why this strategy had been successful. First, it invokes automatic partisan divisions to a lesser extent than discussions about climate mitigation. Some participants felt that conversations about mitigation are often framed as attacks on agriculture or as excuses for additional government action: 10 participants explicitly mentioned agriculturalists feeling on the defensive in climate and water related discussions in general; and 9 mentioned a lack of trust in federal government on the part of ranchers. Six of the participants mentioned that starting with weather and climate effects allows for a large amount of the conversation to take place before disagreements come up, allowing ranchers and climate information providers a lot of common space to work with. The second reason for this strategy was that climate impacts are what ranchers care about more on a daily basis and have a history of dealing with.

Content: Connect content to ranching operations/economy

A related theme was that climate communications should focus on connecting to the actual on-the-ground operation of ranches and the economic case for adaptation (both sub-themes were mentioned by 12 participants each). As one participant put it:

> *"He won't talk to you about why climate change is, who caused climate change. He won't talk to you necessarily about mitigation but he'll say, 'well shit, this is a really important issue. Monsanto just spent a billion dollars on a climate data stock.' It's like, these are really important things for agriculturalists coming down the line and there's a lot of money on the line. …But in terms of the best way to communicate that, I think it's really about recognizing where people are out and maintaining your eye on profitability. I think often there's this very value driven sense on climate change that comes out of the lefty environmental community where this is like, the future generations and our responsibility as stewards and all that stuff. And that doesn't resonate for a lot of folks who are producers. It's also about recognizing like this is a risk to business. It's an opportunity to business. But ultimately if you're not profitable you're going to go out of business. You're not going to be at the table anyway.* ***"Participant "69"***

Participants stated that they believed this strategy was effective because it connected climate and adaptation conversations to what ranchers both cared about and were knowledgeable about – the success of their operations. Additional related subthemes were that climate conversations should provide feasible options for future action (9 participants) and that the ability of ranchers to adapt be framed as a positive and beneficial action, not just as necessary (7 participants).

Process: Acknowledge rancher experience

A broader strategy that was mentioned by most (16) participants as successful at continuing climate and water-related conversations with ranchers was to acknowledge that ranchers (and farmers) already have experience with water management and other adaptation-related activities. Many participants, especially those with experience ranching or farming experience in Montana, described situations where environmental or climate-related groups started off conversations assuming and accusing that ranchers and farmers were not doing anything to manage water. Participants stated that this turns ranchers and farmers off having a conversation because they feel attacked, talked down to, or that the information provider does not understand their context (which ties into the previous strategy):

> *"We all say, we all are very proud about how responsible we are in using the (water) resource. Extremely proud about what we developed and how we have used it to the benefit of not just the individuals but the whole valley. And if you have an outside entity, saying hey, you guys really need to start thinking about how you use it (water), that's like a, wait a second… don't tell us how to do it. We've been doing it for a long time. And if you want to tell us how to do it, at least first come and see how we are using it."* **Participant "86"**

> *"The second thing that maybe it's just side by side with it, is that you never want to tell a rancher what they should do. You create a program maybe on climate change at Stockgrowers (meeting) and then let them ask you what can be done. Because as soon as they start, they feel that you are genuinely interested in their success now they are willing to work for you, with you. If they think, if they get the slightest hint that you're in it to make your sales quota look good, and I'm using that term a little broadly, or because it is a federally directed program, they won't talk to you. I mean, they'll be polite, they'll thank you for your input, and they'll never call you again."* **Participant "70"**

As the above quotes suggest, it is not that participants necessarily think ranchers and farmers won't adapt to changing conditions, but that the participants thought ranchers resent being told what to do by "outsiders" and those whom they believe are ignorant of conditions on the ground. Approximately half of the participants stated that they thought it was the rancher's direct experience with changing conditions that spurred interest in conversations with climate and adaptation specialists.

Process: Increase two-way contact and generate trust

The quote from Participant 70 in the previous section suggests that showing an understanding of ranchers' experience assists in continuing the conversation not only because the rancher might think the communicator is more informed, but also because the rancher may now understand that they have benign intentions. This fits with the literature on the different dimensions of trust (e.g. competency, intention) (Nooteboom 2002). Many of the participants (10) specifically mentioned trust between groups and a total of 13 participants mentioned that some mix of two-way communication, face to face communication, and iterative contact were necessary to generate that trust:

"you hate to say that they're they are not open-minded and actually I wouldn't say that. I think that I think that people in our culture are extremely open-minded but they like to know who they're talking to. And you know frankly it's important that before someone can form a trusting relationship in which they're going to convey information back and forth to someone like…Historically you know they want to know that I have a little bit of dirt on my hands that you know those people understand what it actually means to live and work in an agricultural business every day what the inputs are what the costs are what the sacrifices are how the whole culture and dynamic work" **Participant "64"**

"*Like people are like, who are you? Until you have this either, until you have a known acquaintance who introduces you so you have an introduction. Or you work one on one with people. Like Montana is still small enough that it's just, I can't quite put my finger on it. But in terms of communicating and knowing people around the state, it almost feels like what I would think of as the 50s. I don't actually know if that's accurate or not. But where you knock on doors and shake people's hands. And that's how you communicate and teach and get people to buy in on things here."*. **Participant "67"**

A large part of why these last two strategies may be required for continuing discussions on climate and resource management and adaptation is that most participants expressed concern over what they saw as growing societal divides in Montana. Almost all participants (17) mentioned the distinction between the urban and rural areas and mindsets in Montana. This is unsurprising as One Montana's stated goal is to bridge this divide. Related divides where between scientists/agriculture and environmentalists/agriculture (each mentioned by 12 participants). Other societal divides that were mentioned were between individuals/organizations (10), government/private (9), political divides (7), large land owners/family farms (6), insiders/outsiders (6), recreational user/landowners (4), farmers/ranchers (3), and older people/younger people (3) (see Appendix G for participant quotes regarding divides). The boundary network shown in Figures 4.2 extends and enables access across many of these divides.

Although many participants agreed on what successful strategies are within the Montana context, it is interesting to note that not all participants brought up the same concerns as rationale for these strategies. For example, although at least some members of both the core One Montana group and the Agricultural-focused group mentioned that ranchers specifically feel under "attack" on issues of climate and water, none of the members of the Climate and Adaptation

Science group did. This may simply be an indication that core One Montana members are more similar to Agricultural members than to Science members, which may make sense given their history (One Montana as a group has a longer history of working on agriculture-related projects, and thus had contact with Agriculture group members before helping groups engage on climate issues). It may also be important to note the differences in mental models between Science and Agricultural groups about communications.

Another area where there were distinctions between interview participants is that while most agreed that bridging the rural/urban divide was necessary, some mentioned feeling that One Montana was leaning too much toward rural (1 participant from the Science group) or too much toward urban (4 participants from the One Montana and Agriculture groups) in the newer climate-related work.

4.3 One Montana Rancher Workshop Surveys

Methods

Recruitment: One Montana coordinated two workshops focused on climate adaptation for ranchers: one at the annual meeting of the Montana Stockgrowers Association on December 8, 2016 in Billings, MT, and one with the MSU Extension in Forsyth, MT on December 16, 2016. At the end of each workshop, attendees were asked to fill out our survey, which was voluntary. There was no compensation for participation in the workshop or for filling out the survey.

Participants: Due in part to a mix of scheduling and weather-related issues, only 27 workshop attendees completed the survey (17 out of 60 total attendees from the December 8 workshop, 10 out of 13 from the December 12 workshop). The mean age of participants was 45 and approximately 50% indicated they had at least a bachelor's degree level of education. 56% indicated that ranching was their primary occupation. Participants who indicated the location of their ranch on the survey came from Mccone, Custer, Rosebud, Garfield, Broadwater, Phillips, Beaverhead, and Hill counties. Indicated ranch sizes ranged from 1,000 – 80,000 acres. Table 4.4 summarizes how participants identified themselves politically:

Table 4.4: Breakdown of participant political identity by type of issue (%).

	Very Conservative	Conservative	Moderate	Liberal	Very Liberal
Social Issues	15%	30%	22%	4%	11%
Economic Issues	26%	37%	11%	4%	4%

Survey Protocol: The survey design was informed by the themes that emerged from the interviews and were intended to map onto the influence diagram of interest as shown in Figure 4.5) (Morgan et al. 2002). Appendix H contains the full survey protocol. In particular, the survey was designed to gather information on the following: what prior contact the participants had with workshop organizers, presenters, and other ranchers (Qs 1,2,3,12), their reasons for participating in the workshop (4,15,20), whether they felt affected by changes in weather patterns (10,11), to what extent did they find the workshop informative (5,7,8,16), and to what extent they intend to take future action including seeking additional information (6,13,14),sharing information (9), and taking adaptation actions (17,18). Answer modes varied from short open answers, to multiple choice, to binary yes/no, with most the questions being in the form of statements to which participants indicated their agreement using a Likert-type scale ("1-completely disagree" to "5-completely agree"). Questions that asked about prior contact with or intent to contact other groups also asked which groups. The final section of the survey contained demographic questions including whether ranching was the participant's primary occupation, the location of their ranch, how many years they had been involved in ranching, the size of their ranch, their age, education level, political identity on social issues, political identity on economic issues, and whether they were originally from Montana.

Analysis Plan: Originally, we planned to conduct data reduction and path analysis/multiple regression analysis to determine the relationships assumed in Fig 4.5 As there are several questions related to each of our main variables of interest (prior, affected, inform, "buy-in"), we hoped to analyze how well similar variables measured their underlying construct (e.g. is intent to come back to another workshop, Q5, similar enough to intent to generally seek out future contact, Q13, as measures of "buy-in"). This would help us to determine if we can use the generalized influence diagram or if we need multiple analysis with different measures of "buy-in." Multiple regression analysis would have helped us determine the direction and magnitude of the associations between our variables of interest. The plan was then to use this information to compare the relative strength of the relationships between different predictors of "buy-in". The answers as to who specifically ranchers had been or planned to be in contact with were going to be used to see which part of the boundary network appears to be strengthened by these workshops (e.g. is it just trust in One Montana or partnerships with the Montana Climate Office).

Due to the low number of respondents and the high level of skew in our data set (Table 4.5), we modified the analysis plan to consist of visually describing the raw data and summarizing any relationships using an exact method. We took the original 5-point Likert-scale data and binarized it by pooling any "4" and "5" answers as "1 - agree" and all other answers as "0 - disagree" ("Not sure/I don't know" answers were left as blanks in the data set). The data was split this way as we wanted to separate out firm "agree" answers. We then calculated the Fisher Exact Test p-value (Siegel 1956) for a uni-directional test for each of the 6 bivariate relationships shown in Figure 4.6.

Table 4.5: Descriptive statistics for variables of interest
(Individual responses from 1 – completely disagree to 5 – completely agree).

Variables	**n**	**Mode**	**Median**	**Min**	**Max**	**I don't know/ No answer**
"Prior" - I have discussed strategies for dealing with changing weather patterns before this workshop.	26	5	3.5	2	5	1
"Affected" - Changes in weather patterns have affected my ranching operations.	23	5	5	2	5	4
"Inform" - The presentations at the beginning were informative.	26	5	5	3	5	1
"Buy-In" - I will seek out more information about changing weather patterns in the future.	26	5	5	1	5	1

Results

Figure 4.6 shows the contingency tables and related Fisher p-values (note the arrows have been removed as the relationships are simply associations):

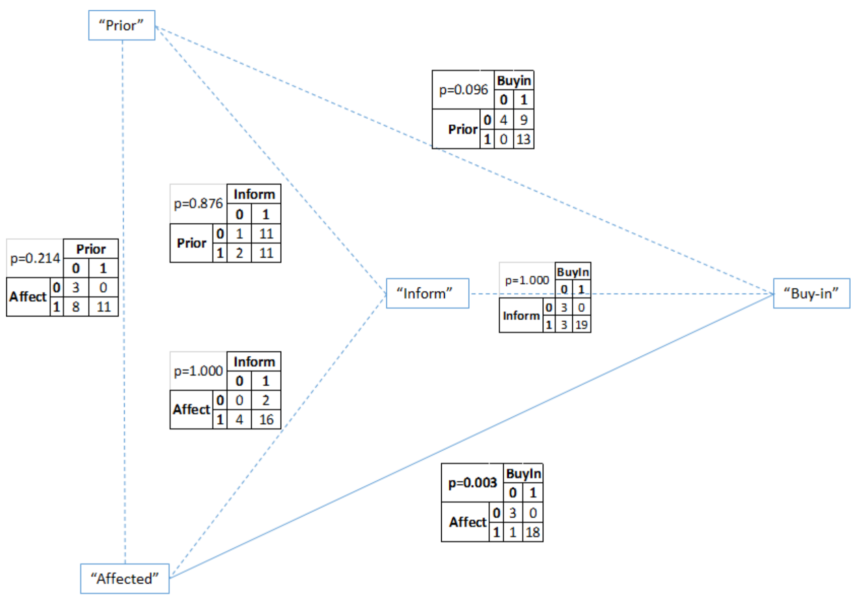


Fig 4.6 Contingency tables and Fischer p-values for each relationship. Solid lines indicate relationship where Fisher $p < 0.05$.

The results suggest that the feeling of having been affected by weather patterns is associated with intending to have future contact/buy-in, whereas the feeling that the workshop was informative does not appear to be. Prior contact may also be associated with "buy-in." Of the 13 participants who indicated that they did not have prior contact, 9 indicated that they would seek out information in the future. The descriptive statistics for the remaining unused variables are shown in Table 4.6:

Table 4.6: Descriptive statistics for additional (unused) variables.
(Individual responses from 1 – completely disagree to 5 – completely agree).

Variables	n	Mode	Median	Min	Max	I don't know/ No answer
The workshop met my expectations.	26	5	5	3	5	1
I will attend similar workshops in the future.	27	5	5	3	5	0
I will share information from this workshop with other ranchers.	24	5	5	3	5	3
Changes in future weather patterns will affect my ranching operations.	24	5	5	1	5	3
I will seek out more information about dealing with changing weather patterns in the future.	25	5	5	1	5	2
My breakout session was informative.	22	5	4.5	3	5	5
I will implement what I learned from the session on my ranch.	18	4	4	1	5	9
Other ranchers will implement what they learned about from the session on their ranches.	16	5	4	3	5	11

As the table shows, most additional variables, like our main variables of interest, were skewed toward the high end. Most survey participants said that they heard about the workshop through the respective workshop sponsor (Stockgrowers Association or MSU Extension). Approximately 50% said they knew either a presenter or an organizer prior to the workshop, with the most frequently mentioned contacts being MSU Extension personnel. 25 out of 27 knew at least one other rancher at the workshop and the average number of other ranchers known was 5-6. When asked to rank which presentation was the most informative, those who answered ranked was the Montana Climate Office most highly. In terms of reasons for not implementing workshop suggestions, the number one reason (with 6 out of 15 participants answering) was not having the physical resources to do so.

4.4 Discussion

In this exploratory study, we attempted to gain a better understanding of the boundary network that One Montana is a part of and helps creates to connect scientists to ranchers and farmers, the context for communication about climate science and successful strategies, and how One Montana's climate resiliency workshops generate more "buy-in" or intention to participate further on the part of ranchers.

Based on both the history of One Montana's Resilient Montana network and the reasons network members said they engaged with One Montana, it appears that One Montana functions very much like both the "ring" in the "key chain" type arrangements of boundary networks which connects disparate groups (i.e. MCO to MSU Extension – see Figure 4.3), and like the center link in the "linked chain" type of arrangement, where they seek to help one side of the network communicate with the other (AGAI with the city of Bozeman, ranchers with climate scientists – see Figures 4.3 and 4.4). A mix of these types of configurations are typical in boundary networks (Lemos et al. 2014). In some cases, One Montana is creating new links between other organizations or individuals (MCO and ranchers), and in other cases they are duplicating connections (between MSU Extension and ranchers - see Figure 4.2). Interview participants supported the importance of prior/iterative contact in wanting to engage the network these additional connections may strengthen existing ones as has been found in other boundary chains (Meyer et al. 2015, Ingold 2017).

In terms of communication strategies, the results of the interviews suggest that network members generally agree on the importance of avoiding content (climate mitigation, assumption that agriculture is entirely at fault/does not act to protect water) and communication processes (disconnected, one-way) that trigger or exacerbate already established divisions between ranchers and scientists in Montana. These are specific examples of strategies that help maintain the saliency and legitimacy criteria that Cash et al. 2003 lay out for such communication. That One Montana's network extends across the political spectrum as well as the rural/urban and scientist/agriculturalist divides may partly account for it being able to serve as a neutral organization. Participants also emphasized acknowledging agriculturalist experience, and that task is made easier for groups associated with the Resilient Montana network by virtue of the network's inclusion of agricultural stakeholders at different stages (local agriculturalists to trade organizations to the Department of Agriculture and MSU Extension). Thus, it appears that there is a good match between the communication strategies mentioned by interview participants and the reach and translation work of the boundary network. Also, in addition to improving communication content by recognizing that some topics are associated with attacks on agriculture, the theme of agriculture feeling under threat was also mentioned as a reason for the engagement of such groups with other parts of the boundary chain through One Montana.

It is interesting that as the boundary network encompasses new groups and individuals that fall in different places along the rural/urban spectrum (as it has with its shift toward climate adaptation discussions) the boundary network itself may build up its own internal tension along those divides. One Montana appears to be aware of this tension as a group and interesting future work could focus on how buy-in to the overall goal of bridging divides helps manage that tension as new network connections are made. One Montana has framed much of its climate communication work in terms of water resources and connected the successful management of those resources with cooperation between rural and urban and between scientist and agriculturalist. This subsuming of the climate communication within the broader theme of closing the societal divides may be part of the reason outside groups see One Montana as less politically motivated than other organizations.

As previously mentioned, our sample size of participants who completed the survey was low and thus our results should in no way be interpreted as conclusive. Results of our descriptive analysis do agree with the established literature on climate change engagement (importance of feeling affected/threatened by changes) (O'Conner 2005).

Part of the purpose of such exploratory studies are highlight specific contexts and generate ideas for future research work. Additional work to compare and categorize interview participants' mental models and how these relate to the network structure and to perceptions of continued divisions in Montana would be worthwhile. It would also be helpful in further identifying the effectiveness of One Montana's efforts specifically, and boundary chains in the climate space in general, to gather additional information on the mental models of network members as the project progresses (for example, to see if the Science and Agriculture group models become more similar through repeated interaction, or what about them becomes more or less similar).

Given the opportunity, it would be helpful to perform follow-up surveys with a larger group of ranchers (including those that did not attend One Montana's workshops) in order to confirm our preliminary results about what leads ranchers to participate, and to understand to what extent if any such workshops increase channels of continued communication between ranchers and climate and adaptation scientists. Also a more focused survey that more clearly differentiated between network connections, communication process, and communication content may provide additional insights and guidance. It would also be of interest to test whether, "bridging the rural/urban divide" is a goal that ranchers share in addition to the networked organizations, and if so how subsuming climate information exchange within that goal assists or constrains climate discussions between groups.

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V. DISCUSSION

The parallel trends of increased polarization of climate and environmental discussions and the increased need for more cooperation and coordination between multiple stakeholder groups in adapting to environmental changes makes it ever more important to study and implement strategies and structures that build, make efficient and sustain discussions between those groups. This dissertation examined these issues in two case studies focused on the use of climate and adaptation information for water management under changing conditions; one in Guanacaste, Costa Rica and one in Montana, USA. Both study areas are predominately agricultural regions experiencing ongoing socio-economic transitions as well as differing climate impacts. In both cases, the research examined the mental models of diverse stakeholders, whose communication and coordination affect their region's well-being. Both case studies also looked issues related to the role of boundary organizations in bridging stakeholder groups. In Guanacaste, the research focused on exploring the environment in which boundary organizations may be useful. In Montana, the research focused on examining an active boundary network that is connecting climate scientists to agriculturalists.

The three main chapters of this dissertation consist of individual papers (1 published, 2 being prepared for publication) that touch upon different aspects of this space: comparing group perceptions (Chapter 2), how trust in different groups affects the use of forecast information (Chapter 3), and how different groups and individuals engage or "buy-in" to climate information boundary chains (Chapter 4). This final chapter presents brief discussions of the main themes from the three papers and future research. After summarizing major patterns in the results (Section 5.1), their theoretical implications are considered (Section 5.2), followed by directions for future research (Section 5.3).

5.1 Communication and Engagement Patterns

Many of our findings in both Guanacaste and Montana reflect divisions between stakeholder groups that corrode the trust and coordination necessary to share climate and adaptation information and respond successfully to environmental changes.

In Guanacaste, we found differences between Large stakeholder groups (government, hydroelectric, large farmer/rancher) and Small ones (small farmer/rancher, local water councils named ASADAs, tourist groups, public) in their perceptions and use of climate information. Rural smallholder farmers and ASADA members typically expressed the view that forecasts were not good enough because the forecasts didn't match the scale of their farm or ranch and because forecasters don't understand their specific area. Large groups appeared to be more connected with one another than were Small groups. Also, from the second study, we found that trust in local informal forecasts sources, which is higher among ASADAs than among the larger Aqueduct agency members, appears to be negatively associated with the use of formal season forecasts.

Previous work in the Guanacaste has established that there is fractured water governance that separates decision makers at different scales through a lack of coordination and communication (Kuzdas et al. 2015). This fracturing is problematic because both types of groups coexist and need to work together on water management issues, and climate information needs to be shared both ways. What our work shows is that in addition to not being connected to each other, Large and Small groups have different perceptions of the water system and climate information, which could suggest that even when there is contact between groups, there may be a higher chance of misunderstanding, especially over the complexities of the water system and scale of forecast information. What this means in terms of thinking about boundary organization work in the region is that it is needed not just to connect across the different geographic scales but also to translate values and scientific information between Large and Small groups.

In Montana, much of our discussions with boundary chain members turned to the issue of the societal divides that shut down communication and which are the hurdles that many of the communication strategies proposed by the interview participants sought to overcome. The most mentioned divides concerned urban groups and scientists on one side, and rural groups and agriculturalists on the other. Network members that participated in our study were also generally in agreement regarding climate-related communication with ranchers: it is important both not to engage in ways viewed as attacks on agriculture and to make attempts to understand and respect local agricultural contexts. The structure of the boundary chain that One Montana has helped create reflects the context of the societal divides (it is made up of groups from both sides) and appears to enable the suggested communication strategies in part because of this.

5. 2. Boundary chain engagement, success and tension

In Montana, we found that the organization One Montana already plays both a connecting and translating role in the Resilient Montana boundary chain between rural agricultural stakeholders and urban climate adaptation scientists. We additionally found suggestions of why organizations and individuals engage with the boundary chain and how they do.

Organizational engagement with the boundary chain appeared to be prompted by prior contact, a respect for the overarching goal of "bridging the rural/urban divide", in addition to the need for the connecting and translating work that One Montana does. Of additional interest is that some of the perceived need for connection and translation work appears to come from a defensive stance that rural/agriculture groups are taking. While the defensiveness of agricultural groups and the wariness of (what may be perceived to be) uniformed outsiders are seen as causes of the divide from urban/scientist groups, these positions also appear to spur interest in participating in boundary events (such as workshops) and/or organizations/chains. For example, worried about the more populous city outvoting or moving faster than them on water-related issues, irrigators wanted to be a part of the decision making process earlier on and did so through a boundary organization that exists to make such connections and inclusions. Our limited survey results support a less socially focused version of this defensive impulse, in that ranchers who feel that they have by affected by changing conditions appear to be more likely to seek further engagement.

One common theme in these results is that these interactions are iterative: becoming connected, for whatever reason, leads to discussions that increase awareness of other parts of the system and further discussions. This "continued conversation" appears to be the measure of success of One Montana and of boundary chains in general. If those interactions are positive, this may in turn generate trust in members of those other parts, even if groups originally joined the network to protect themselves. This could be because exposure leads to acknowledgement of competency or leads to understanding that the other side isn't trying to attack. Taking away the fear of attack and instilling confidence in the science will likely lead to either a desire for more connection or at the least an acceptance of interaction. The implication is also that it is not enough just to connect disparate groups, boundary organizations and chains should endeavor to support ongoing interactions across the divides of interest.

Some of our findings also suggest that there can be a growing tension within the boundary chain itself as newer projects, (such as potentially contentious ones involving climate information) are taken on and more groups added. Members of the One Montana network newly worrying about whether the focus has shifted too much toward urban or rural is one example of this from our work. Another is that some mentioned that other groups outside of One Montana were wary of connecting because of who One Montana was already connected to. This suggests additional complexity to the discussion of successful boundary chains as described in the literature. In their work, Kirchhoff et al. discuss *embeddedness* (or the level at which each group in the chain affects the actions of other groups) as a needed component of synergy in a boundary chain (Kirchhoff et al. 2015). But, being affected by other groups may evoke suspicion from groups farther away (socially) from each other who are now connected. This tension is part of the functional role that boundary chains play in bridging disparate groups that might be at odds with each other, but there may be residual historical or political wariness of giving up control to the other side of the divide.

What the overall goals of the network are may play an important role in subsuming or managing these tensions. In Guanacaste, where climate change is less politically charged (though this may be changing), it may be that a climate science focused and directed network works well. In Montana (and maybe more broadly in the US), it may be that subsuming climate-related discussions within the larger context of bridging communities is more effective at facilitating connections and information transfer on this topic. The idea of using a broader "connecting our communities is the overall mission" message may also be beneficial as external conditions continue to change around the network.

5.3 Future research

There are several extensions of the work in this dissertation that would assist in further investigating how boundary chains form, manage internal and external tension, and enable successful communication across societal divides.

1. The finding that defensive postures on the part of local stakeholders may both pose challenges to communication and prompt those stakeholders to connect to boundary groups (or otherwise be able to share their own knowledge) invite study of how and when such postures spur opposite responses.

2. The finding that tensions within the boundary chain may be more manageable when there is “buy-in” to larger goals, such as “bridging the rural/urban divide” of “expanding environmental conscientiousness,” leads to the questions of when and where this is an effective strategy for maintaining a boundary network. How individuals “buy-in” to such messages differently from how organizations “buy-in” would also be worth study.

3. A related question is when a boundary chain’s mission is compromised by engaging with additional different groups under a larger umbrella (somewhat analogous to should a “Fake News” operation be allowed into the chain of news agencies). For example, the desire to keep groups together could might prevent a boundary chain on climate adaptation from ever moving on to mitigation. In more theoretical terms, at what point does embeddedness become too constraining? One way to approach this question is by measuring the “tension” within a boundary chain and its effects on the connection and flow of information and resources.

4. It has been pointed out in the literature that adaptive water management (which seeks to react to new information more rapidly and be more flexible) can be at odds with integrated water resources management (which seeks to include additional groups, goals, and resources). A topic

for future research is how this tension is reflected and addressed in boundary chains related to climate and water system adaptation.

5. As boundary chains may connect organizations across larger societal divides, it would be interesting to study how aware different parts of the network are about the constraints and motivations of other parts of the network, and how this awareness changes over time. Having an accurate way of measuring how aware different parts are of each other may assist in two ways. First it may assist those more distant groups in making informed decisions about whether to join, leave, or remain in a particular network. Second, it may assist the more intermediary groups in understanding where areas of misunderstanding may arise in the network and perhaps what level or type of resources are required for transforming this misunderstanding.

Answering some of these questions may additionally help boundary organizations and chains make informed decisions about where and how to spend their resources and connections in ways that lead to their desired goals.

5.3 Conclusion

As the world seems to grow more complex and move at a faster clip and the underlying factors that models are built upon change, it is important to understand what is going on on-the-ground. The descriptive, exploratory studies that make up this dissertation hopefully do that to some extent in terms of how stakeholder groups are interacting with each other and allowing or not allowing informed decision making to occur in the regions of interest. In general, they help add evidence to the importance of listening to different groups and understanding their interactions as a first step to support informed decision making and in the analysis of boundary chains.

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APPENDICES

Appendix A: Description of Guanacaste, Costa Rica

The research conducted for studies 1 and 2 was conducted as part of the FuturAgua Project in Guanacaste, Costa Rica, a multidisciplinary, multinational research effort supported by the G8 Belmont Forum to study climate change and freshwater security in developing nations (FuturAgua 2015). Guanacaste is a seasonally dry tropical province in the northwest of the country located between the Pacific Ocean and the central mountain range (Figure A.1). The area's yearly rainfall pattern that is typically comprised of a 6-month dry season from late November until May, a lesser rainy season from May to July, a mid-summer "drought" in July/August, and the greater rainy season from August to November (see Figure A.2). This pattern is significantly affected by the status of the El Niño Southern Oscillation and the North Atlantic Oscillation climate systems. Climate change models and scenarios, such as those included in the Fourth and Fifth Assessment Report of the IPCC, predict changes to the annual cycle of precipitation and increased temperatures, both of which may additionally stress water supplies in the region (Rauscher et al. 2008; Rauscher et al. 2011; Karmalkar et al. 2011; Ryu and Hayhoe 2014; Neelin et al. 2006; Steinhoff et al. 2014). Previous studies in the country have found that there is high level of acceptance that climate change is occurring (Vignola et al. 2013).

Figure A.1 Location of study area. Map data: Google 2014

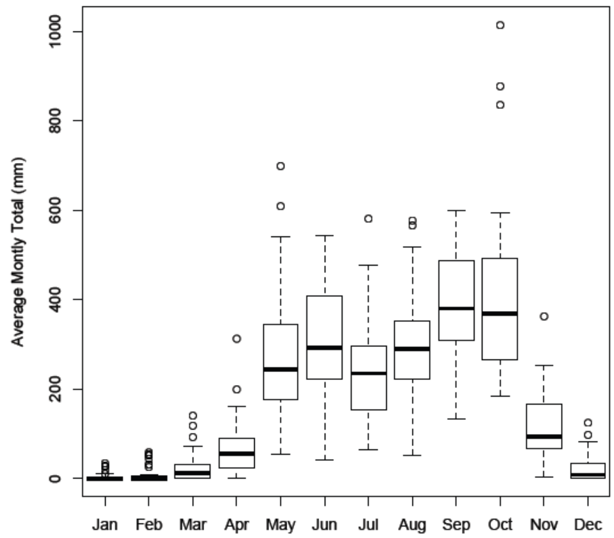

Figure A.2 Average monthly rainfall in Guanacaste Province (solid bar = median, box = ± 1 quartile, whiskers = ± 1.5 times the interquartile range). Data are from NOAA Global Historical Climatology Network-Monthly v3 dataset for the Nicoya weather station from 1949 to 1986 (NOAA, 2011). Historically there has been a two-hump pattern with rains starting in May, a mid-summer lessening of precipitation in July, and the main rainy season commencing in August and lasting until November.

Guanacaste is not homogeneous in climate or water demands. Figure A.3 shows six important sub-regions in the province:

Figure A.3: Important sub-regions of Guanacaste. The divisions in this figure are not exact but are meant to give a general idea of the locations of different regions. 1 = the volcanic highlands, where there is more rainfall and where many of the hydroelectric facilities are located; 2 = the Arenal-Tempisque Irrigation District, a government irrigation project that takes water released from the hydroelectric facilities and distributes it to farmers; 3 = the central plateau, which is drier than other areas on average but has a large amount of the population and agricultural enterprises; 4 = a more mountainous region that sees more precipitation than the central plateau; 5 = the Potrero-Caimital watershed and Nicoya area, where much of the other FuturAgua research work is taking place; and 6 = the Pacific coast, where there are a number of tourist developments

The total area of Guanacaste is approximately 10,000 km^2 and the total population is approximately 354,000 (~ 7% of the total population of the country), making Guanacaste the least densely populated province in Costa Rica (INEC, 2015). Historically, economic and cultural activity in Guanacaste centered on cattle ranching. As of 2010, 25% of the population is occupied in the Business, Restaurant, and Hotel sector, approximately 25% in other public and private services, 20% in agriculture, 10% in construction, and the remainder in textiles, transportation, water/energy, real estate, and financial services (CATURGUA, 2010). The current literacy rate in Guanacaste is 95%. Per capita income in Costa Rica is $13,600, and the World Bank classifies the country as having an upper middle income level that is higher than most other developing nations (World Bank, 2015).

Costa Rica guarantees a healthy environment to its citizens in the national constitution and has passed water related laws that establish that freshwater resources cannot be privately owned. The Water Directorate of MINAE, the Costa Rican Ministry of the Environment and Energy, manages concessions of groundwater and river water for use by municipalities, hydroelectric power facilities, and private entities such as farms, off-grid households, and resorts. Within the last 30 years, municipal population growth, changing agricultural activity, increased hydro-electric power production, increased tourism developments, and continuing environmental protection interests all have placed increasing demands on freshwater resources and there has been a recent history of inter-stakeholder group conflict over water issues (Ramírez-Cover 2008). These conflicts have been shown to occur in part due to underrepresentation of local stakeholders in decision making. In addition, there is a lack of credible or available scientific measures of water quality and quantity, and without these measures the ability to distinguish between the physical lack of water resources and misallocation of such resources has proven difficult (Kuzdas 2012 and van Eeghan 2011).

Local and Regional Stakeholder Groups

The government agencies that make decisions at a local and regional level about water resources or are impacted by such decisions include MINAE as mentioned above, the Ministry of Aqueducts (AyA), the Ministry of Agriculture and Livestock (MAG), and the Ministry of Subterranean Water and Irrigation (SENARA). AyA is mandated to provide potable water to all citizens in the country for domestic use. In the larger towns and cities, AyA manages the water systems, whereas in the smaller less-connected towns the water systems are managed by local water committees or ASADAs. The executive council of each ASADA are volunteers that are voted in by the users every 2-3 years (some ASADAs pay the administrators and technicians that work on the systems). The volunteer councils are legally responsible for maintaining the water systems and have the authority to collected water use fees, but typically have less technical expertise then the central AyA offices. Almost all municipal water systems in Guanacaste source their water from groundwater or rivers.

The Ministry of Agriculture and Livestock (MAG) is mandated to provide technical assistance to Small Farmers and this outreach includes assistance with irrigation and climate adaptation efforts. Small farmers are either tenants of Large Farms or family enterprises who either raise cattle or grow a variety of crops for local and sometimes export markets (rice and sugar, but also peppers, coffee and vegetables). Large Farms are large estates used either for cattle grazing or for the growing of cash crops such as rice, sugar, and/or melons and employ agronomic engineers as well as large numbers of laborers/tenant farmers. Large and Small farms typically use a mix of direct rainfall, groundwater, and river water depending upon their location and crop. Depending on the farm type they have a mix of irrigation methods installed on their property (this is more widespread on Large Farms, but Small Farms may also have their own systems). In special irrigation districts, SENARA is responsible for providing irrigation water to Small and Large farmers.

Hydroelectric power generation in Guanacaste comes from the ArCoSa system (3 plants in series for a total capacity of 360 MW) operated by the Costa Rican Electricity Institute or ICE, and a two plant system run by the rural electrification cooperative, COOPGUANACASTE. These systems are located in the mountainous region along the eastern border of the Province which receives a larger amount of yearly rainfall and use a mix of reservoir and river water.

Available Climate Information

The main source of climate forecast information in the region is the Costa Rican National Meteorological Institute (Spanish acronym, IMN). The IMN provides daily and weekly weather forecasts through its website (IMN 2016). The IMN also provides for free on this website monthly climate reports that review the past months precipitation and temperature data and project future precipitation by region typically up to three months ahead (IMN also less frequently releases predictions for the next 6-12 months). Internet coverage in Guanacaste is relatively good and many access the internet through mobile devices (especially younger generations). Additionally this information is also transmitted through local and national public media (TV, radio, and newspapers). The IMN also provides more detailed historical data to the public and other government agencies, though for a reportedly hefty fee. The other government agency that has direct access to climate measurements is ICE, though typically ICE does not share this information. ICE also has information regarding reservoir levels that is used in the management of hydroelectric power stations. Many Large Farmers have their own meteorological equipment and have access to NOAA forecast information. Streamflow and groundwater data are more difficult to come by and this lack of information about how much water exists in certain aquifers has been identified as a factor in local water conflicts (Kuzdas 2012 and van Eeghan 2011). Universities on average are well regarded as honest information sources, while generally levels of trust in the government are more mixed.

Appendix B: Interview Protocol for Study 1 (English Version)

A Spanish language version of the following protocol was used to guide the interviews:

Introduction:
My name is __name_____ and I am a student from __institution_____. I am a member of the FuturAgua research project. As part of a scientific study, we are interested in knowing your views about water systems in Guanacaste. We are interested only in your opinion and so there are no right or wrong answers. During the interview, I may ask a question more than once in order to make sure that I understand what you are saying.

This interview is completely voluntary and confidential. I would like to record the interview, so that I don't have to take notes and instead can focus on what you are saying. Please do not share any identifiable information or names of people you know as examples during the interview. If you feel uncomfortable answering any question, let me know and we can skip that question and go on to the next one.

The interview will take about 1 hour. You must be 18 years or older to participate.
Do you have any questions before we start?

I will be starting the interview recording now. Is this okay with you?

Questions:
I. Stakeholder Perceptions of Water Resource SES (social-ecological systems)

The first thing I would like to talk about today is the water resources here in [local location].
1. Please tell me about the state of water resources here in [local location]. Can you tell me more about water resources here? What about in other areas of Guanacaste?

Potential Follow-ups:
a. Tell more about whether the amount of water [from rain/in the ground/in the rivers and lakes/from the aqueduct] is enough or not enough for your needs/others/the environment? Why is the amount of water enough or not enough?
b. What happens when the amount of water is low? Why?
c. Is the surface water, such as in rivers and/or lakes, safe for human use? Is the groundwater safe for human use? Is the surface water safe for other uses? Is the groundwater safe for other uses? Why?
d. Tell me more about the quality of the [specific type(s) of water resources]. Is the water clean or contaminated? Why is the water quality like this?
e. What happens when water quality is low? Why?
f. What do you use water for? What are the sources of water that you use and/or manage for the use of others? What could you use water resources for? What do others use water for? How is water used in the environment? How is water used in the local economy?

2. Can you describe how the amount of rainfall varies over a year?
a. Is this pattern always the same each year?
b. Has this pattern changed in the past? Has it changed over the past 10 years? How? Why?
c. Do you think this pattern will change in the future? Will it change in the next 5 years or next 50 or next 100? How? Why?

3. Can you describe how the temperature varies over a year?
a. Is this pattern always the same each year?
b. Has this pattern changed in the past? Has it changed over the past 10 years? How? Why?
c. Do you think this pattern will change in the future? Will it change in the next 5 years or next 50 or next 100? How? Why?

4. Can you explain how the current pattern of rainfall affects you? When are the most critical times of the year in terms of water resources for you?
a. Why is this time period/are these time periods critical?
b. What about this time period is/these time periods are critical (amounts of water, timing)?
c. Are there times that will become critical if water availability changes in the future? Why?
d. Is there a part of the year in which changes in precipitation would be particularly detrimental to you? Why?

5. How do you manage the situation when there is less water than you need? Why would there be less water than you need?

6. How do you manage the situation when there is more water than you need? Why would there be more water than you need?

7. Can you tell me about short term extreme precipitation or temperature events? Can you describe how they affect you/affect others?

8. How do you manage the situation when the quality of water is low or changes? Why would water quality be low? Why would water quality change?

9. Tell me how the way you [various actions depending on stakeholder: operate your business/farm your land/provide electricity/make regulations/use water resources] might affect the water resources available for everyone else. Anything else?

II. Stakeholder Perceptions and Use of Information related to Water Resource SES

10. How do you know when water resources are going to be [limited/abundant/contaminated/ clean]? How do you know what impact this will have?
a. Where do you go to get your information from? Why?
b. Who do you talk to? Why?
c. When do you know? Why?
d. When do you need to know? Why?
e. Is that always how you know? Why?

11. On a scale of 1 to 10 [describe scale], how sure are you that you know when the water resources will be [limited/abundant/contaminated/clean]? Why?

You mentioned [ ] as a source of information. On a similar scale from 1 to 10,
12. How accurate is that source (to what extent do you think they know the reality)? Why?
a. Does the accuracy change depending on how far into the future these events are? Why?

13. With what certainty does that source provide information?

14. How trustworthy is that source (to what extent do you think they tell you what they really know)? Anything else?

15. Can you tell me about other ways you could know when water resources are [limited/abundant/contaminated/clean]? Anything else?

16. What else would you like to know about the state or impact of water resources that you don't know?
a. Why would you like to know that?
b. Is that possible to know? Why/Why not?

17. Do you have to be absolutely sure about when resources will be [limited/abundant/contaminated/clean] in order to take actions related to water resources? Why?
a. If not, how certain do you have to be? Why?
b. How certain can you be? Why?
c. Are different actions taken, depending upon how sure you are? Why?

III. Stakeholder Perceptions and Use of Forecasts and Scenarios

18. What can you tell me about rainfall forecasts?
a. Over what time period and geographic scales do they cover?
b. How do you get such forecasts?
c. Who gives them to you?
d. What do they look like/sound like?
e. What do you think of them? What do you like or dislike about them?
f. Can you tell me about a forecast that you have seen or used?

19. Tell me how forecasts are considered when you manage water resources.
a. If they are not considered, why and how might they be?

20. On the scale of 1 to 10, how accurate are such forecasts? Why?
a. How accurate have the forecasts been that you have used/seen?

21. With what certainty are such forecasts presented?

22. What can you tell me about climate scenarios? What about climate models?
a. What time periods and geographic scales do they describe?
b. Which specific scenarios and models are you familiar with?
c. How do you get such scenarios?
d. Who provides them to you?
e. What do they look like/sound like?
f. What do you think of them? Do you trust them? What do you like or dislike about them? Why?

23. Tell me how such scenarios and climate models are considered when you manage water resources.
a. If they are not considered, why and how might they be?

24. Can you tell me about climate change?
a. Is climate change occurring? If so, why?
b. Does climate change affect you? If so, how?

25. Where do you learn about climate change from?
a. If scientists, how do you think scientists know about climate change? What tools do they use? How much do you trust scientists?
b. If media, where do you think the media gets its information about climate change from? How much do you trust these news sources?

26. Is there anything else you would like to mention about forecasts or scenarios or water resources in general?

IV. Demographic Questions:

27. What is your age?
28. What is your occupation?
29. What is your official job title (if you have one)?
30. What do you see as your professional role?
31. What kind of training do you have?
32. What education levels have you completed?
33. How long have you been in your current position?
34. How long have you been with your current organization?
35. Are you affiliated with any other organizations?

Conclusion:
36. We will be performing a larger survey related to this topic. Can you think of one question you would like to add to this survey?
37. What did you think about participating in this interview?
38. Do you have any additional questions for me?

You can contact ___email1__ or ___email2__ for more information about this research project. Thank you for your time.

Appendix C: Full List of Codes used for Study 1 analysis with descriptions

Table C.1 Full List of Codes used for Study 1 with descriptions

Codes	Drivers
NATURE	Natural cycles (not El Nino) or Nature as force of its own
DEFOREST	Deforestation (both clear cutting and agricultural burns)
GEO	Geography (Atlantic/Pacific side of mountains) or Geology (soil types, earthquakes)
POP	Population growth (demand growth) within locality
GOD	God controls seasons, rains, etc.
CCGW	Global warming type climate change
ELNINO	El Niño/La Niña cycle
OZONE	Ozone hole
TOURISM	Tourism demand (pools, hotels, lawns, recreation)
INDUSTRY	Industry
LGFARM	Large farm demand for water and contamination releases
CONTAM	Contamination of water
OTHERPOP	Water demand from other municipalities
MISUSE	Using water for the incorrect purposes (washing cars, watering lawn, planting melon) or using water inefficiently
ENERGY	Water demand of hydropower facilities
DAMAGE	Damage to aqueduct system
SLR	Sea level rise
RAIN	Amount and timing of rainfall
WIND	Magnitude, direction, and timing of wind
ENERGY	Hydroelectric demand for water
WETSEASON	Timing and duration of the wet season
DRYSEASON	Timing and duration of the dry season
Codes	**States (the state of…)**
COSTS	Economic costs of water or energy
PESTS	Agricultural pests
HEALTH	Human health
RAIN	Amount and timing of rainfall
WIND	Magnitude, direction, and timing of wind
WETSEASON	Timing and duration of the wet season
DRYSEASON	Timing and duration of the dry season
TEMP	Ambient temperature
WATER	The amount or quality of water (no specific water resource mentioned)
GW	Groundwater
RIVER	Rivers and streams
LAKE	Lakes and reservoirs
AQUEDUCT	Aqueduct distribution system
FLOOD	Floods
DOWNPOUR	Downpours, heavy rains
STORM	Tropical storms
IRRIGATE	Irrigation systems
FIRE	Wildfires
CONFLICT	Human conflict over water resources
OCEAN	Ocean and beaches
Codes	**Water Uses**

HOUSEHOLD	Domestic use
ANIMALS	Livestock
ENERGY	Hydroelectric power production
TOURISM	Tourism demand (pools, hotels, lawns, recreation)
CROPS	Small and large scale agriculture
ENVIR	Left for the environment, national parks, biodiversity
Codes	**Management Actions**
CHANGEMIND	Change people's hearts and minds, increase conscientiousness
REFOREST	Reforestation efforts
SAVE	Storing water for future use
PROTECT	Protect watersheds and water sources
NOCONTAM	Stop contaminating water sources
OMR	Normal operations, maintenance, and repair of systems
EFFICIENCY	More efficient use of water
TREAT	Treating water to clean contamination
MODPLAN	Modifying different planning and operations
NOTHING	Nothing can be done/what we do has no effect
NEWSUPPLY	Find/access new supply of water
LAW	Make laws or regulations about water
IMPROVEDTECH	New seeds, improved irrigation etc.
INSURE	Participate in crop insurance
MEGA	Either diverting water from government irrigation district for municipal use or taking water from Atlantic side of central mountains
Codes	**Information Sources**
DEEC	Direct experience and environmental cues
TRADITION	Traditional methods of forecasting: Las Pintas, the moon, birds, flowering
LGOV	Local government: ASADAs
RGOV	Regional government: AyA, MAG, MINAE, SENARA
NGOV	National government: IMN, AyA, ICE
INTL	International sources: NOAA
PRIVATE	Private sources: either Large Farms or Laboratories
UNI	Public Universities
ORG	Non-governmental organizations
SMT	Scientific measurement and testing
Codes	**Information Attributes**
UNCERTAIN	The information is uncertain
VARIABLE	The phenomena is variable
POSSIBLE/NOTPOSSIBLE	It is possible/not possible to know about that phenomena (general)
ONLYGOD	Only God knows what will happen in the future
EXPERTS	Information is trusted because it is made/provided by experts
USED/NOUSED	The information is used/not used
MATCH	The information is accurate because it matches what I experience
NOMATCH	The information is not accurate because it does not match my experience
NOCOMS	The information is not trustworthy because there is bad communication
FRAGMENT	The information I want is fragmented and hard to access
PUBLIC	The information is trustworthy because it comes from a public source (university)
RATING	Indicates where an accuracy or trust rating was provided
NEED	Indicates where a specific information need was mentioned

Appendix D: Survey Protocol for Study 2 (English Version)

Carnegie Mellon University
Engineering and Public Policy

Survey about the perception and use of climate forecast information in Guanacaste, Costa Rica

Primary Investigator: Matthew Babcock (mbabcock@andrew.cmu.edu)
Other Investigators: Gabrielle Wong-Parodi (gwparodi@gmail.com), Mitchell Small (ms35@cmu.edu), Iris Grossmann (iris.gross10@gmail.com)

Study Purpose: This study is part of the FuturAgua research project. You will be surveyed about your opinions on the use of information in the management of water resources in Guanacaste.

Study Details: The survey will take approximately 20-30 minutes. There is not compensation for responding to the questionnaire. The survey is voluntary and all of the personal information will be kept confidential. If you do not want to answer a question, you can skip it. You need to be at least 18 years old to participate. If you have questions or concerns, please contact Matthew Babcock (mbabcock@andrew.cmu.edu).

1. I am at least 18 years old.
- ❍ Sí (1)
- ❍ No (2)

2. I have read and understand the above information.
- ❍ Sí (1)
- ❍ No (2)

3. I want to participate in this research and continue with the survey.
- ❍ Sí (1)
- ❍ No (2)

PAGE 2

Good! You can see what percentage of the survey is left to complete in the progress bar at the top of each page.

PAGE 3

To start, we would like that you think about your role in the management of water resources. Everyone of us uses water daily. But, some people also are involved in the provision and management of water. Please think about your relationship with water in your daily activities.

4. In a few sentences please describe this relationship:

5. When you think about your experience with water resources, which of the following catagories best describes your experience? (Please select the response that most identifies you)

- Above all, I USE water in my daily activities (1)
- Above all, I PROVIDE (or manage) water in my daily activities (2)

Please respond to the following questions considering your relationship with water as a USER or PROVIDER.

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6. We would like to know if you use different types of forecast information in your decisions and actions to manage water. Please indicate which of the following types of forecast information you use regularly (mark all of the options that apply).

- Weekly rainfall forecasts (1)
- Seasonal rainfall forecasts (2)
- Yearly rainfall forecasts (3)
- Multi-year rainfall forecasts (4)
- Groundwater level forecasts (5)
- Traditional forecasts (las pintas, la luna, etc.) (6)
- River level and flow forecasts (7)
- Reservoir level forecasts (8)
- Economic forecasts (energy, land, or crop prices) (9)
- El Niño forecasts (10)
- Other types of information (11)

7. If you marked "Other types of information", please indicate which below:

8. ¿How do you get this information? (mark all of the options that apply)

- Radio (1)
- Television (2)
- Official reports (3)
- Newspaper (4)
- Talks/Meetings/Workshops (6)
- Internet (8)
- Friends and Family (9)
- Other option

9. If you marked "Other option", please indicate which below:

PAGE 5

Next, we present to you 3 rainfall forecasts and some questions about each forecast. If the forecast does not appear, please wait a minute. For the purposes of this survey, the phrase, "managing water resources" means to make decisions and take actions to ensure there will be a sufficient amount of water every time you need to satisfy your needs, or the needs of those to whom you provide water.

PAGE 6 (Note pages 6,7,8 are presented in random order on the online version)

Example: Forecast for 4 days.

	Martes	Miercoles	Jueves	Viernes
Pacífico Norte	am: Poca nubosidad. pm: Parcialmente nublado con posibles lluvias dispersas.	am: Nubosidad parcial. pm: Nubosidad de parcial a total con lluvias y chubascos aislados con tormenta.	Parcialmente nublado	De parcialmente nublado a nublado con aguaceros aislados por la tarde
TEMPERATURAS EXTREMAS (°C)	35/24	35/24	34/19	32/19

10 According to this forecast, for which day is rainfall possible but not necessarily expected?

- Martes (1)
- Miercoles (2)
- Jueves (3)
- Viernes (4)

11. According to this forecast, when is rain expected in the next four days?

- Martes y Miercoles (1)
- Miercoles y Jueves (2)
- Miercoles y Viernes (3)
- Jueves y Viernes (4)

12. According to this forecast, which two days have the highest temperatures?

- Martes y Miercoles (1)
- Miercoles y Jueves (2)
- Miercoles y Viernes (3)
- Jueves y Viernes (4)

13. Please indicate what accuracy you would assign to this type of forecast in general on the scale from 1 (not accurate at all) to 5 (perfectly accurate):

- 1 (1)
- 2 (2)
- 3 (3)
- 4 (4)
- 5 (5)
- I don’t know (6)

14. In one sentence, please explain why you gave this rating:

15. Please indicate if this type of forecast seems useful to you in managing water resources on a scale from 1 (not useful at all) to 5 (very useful)

- 1 (1)
- 2 (2)
- 3 (3)
- 4 (4)
- 5 (5)
- I don't know (6)

16. In one sentence, please explain why you gave this rating:

17. Please indicate if you would use this type of forecast for managing water resources on a scale from 1 (never) to 5 (always)

- 1 (1)
- 2 (2)
- 3 (3)
- 4 (4)
- 5 (5)
- I don't know (6)

18. Now consider the situation in which the forecast that they give later contradicts (does not match) the reality. Please indicate what accuracy you would give to this type of forecast in general on a scale from 1 (not accurate at all) to 5 (perfectly accurate):

- 1 (1)
- 2 (2)
- 3 (3)
- 4 (4)
- 5 (5)
- I don't know (6)

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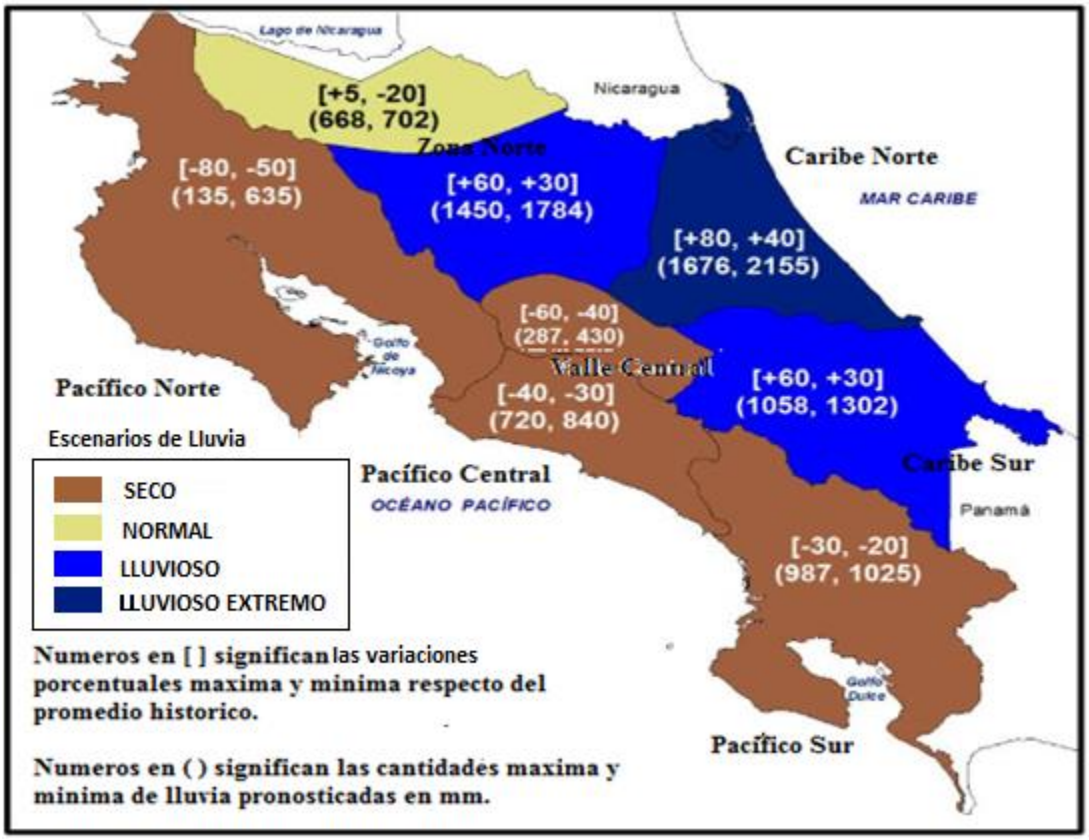
Example: Forecast for 3 months (seasonal).



19. According to this forecast, what will be the maximum amount of rain Guanacaste will receive in the next 3 months?

- ❍ 840 mm (1)
- ❍ 635 mm (2)
- ❍ 1784 mm (3)
- ❍ 720 mm (4)

20. According to this forecast, how many regions will receive less rain than the historical average in the next 3 months?

- ❍ 8 regions (1)
- ❍ 5 regions (2)
- ❍ 4 regions (3)
- ❍ 1 region (4)

21. According to this forecast, which region will have the most negative percentage variation from the historical rainfall average in the next 3 months?

- Zona Norte (1)
- Pacífico Norte (2)
- Valle Central (3)
- Caribe Norte (4)
- Pacífico Central (5)
- Pacífico Sur (6)
- Caribe Sur (7)

22. Please indicate what accuracy you would assign to this type of forecast in general on the scale from 1 (not accurate at all) to 5 (perfectly accurate):

- 1 (1)
- 2 (2)
- 3 (3)
- 4 (4)
- 5 (5)
- I don't know (6)

23. In one sentence, please explain why you gave this rating:

24. Please indicate if this type of forecast seems useful to you in managing water resources on a scale from 1 (not useful at all) to 5 (very useful)

- 1 (1)
- 2 (2)
- 3 (3)
- 4 (4)
- 5 (5)
- I don't know (6)

25. In one sentence, please explain why you gave this rating:

26.Please indicate if you would use this type of forecast for managing water resources on a scale from 1 (never) to 5 (always)

- 1 (1)
- 2 (2)
- 3 (3)
- 4 (4)
- 5 (5)
- I don't know (6)

27.Now consider the situation in which the forecast that they give later contradicts (does not match) the reality. Please indicate what accuracy you would give to this type of forecast in general on a scale from 1 (not accurate at all) to 5 (perfectly accurate):

- ❍ 1 (1)
- ❍ 2 (2)
- ❍ 3 (3)
- ❍ 4 (4)
- ❍ 5 (5)
- ❍ I don't know (6)

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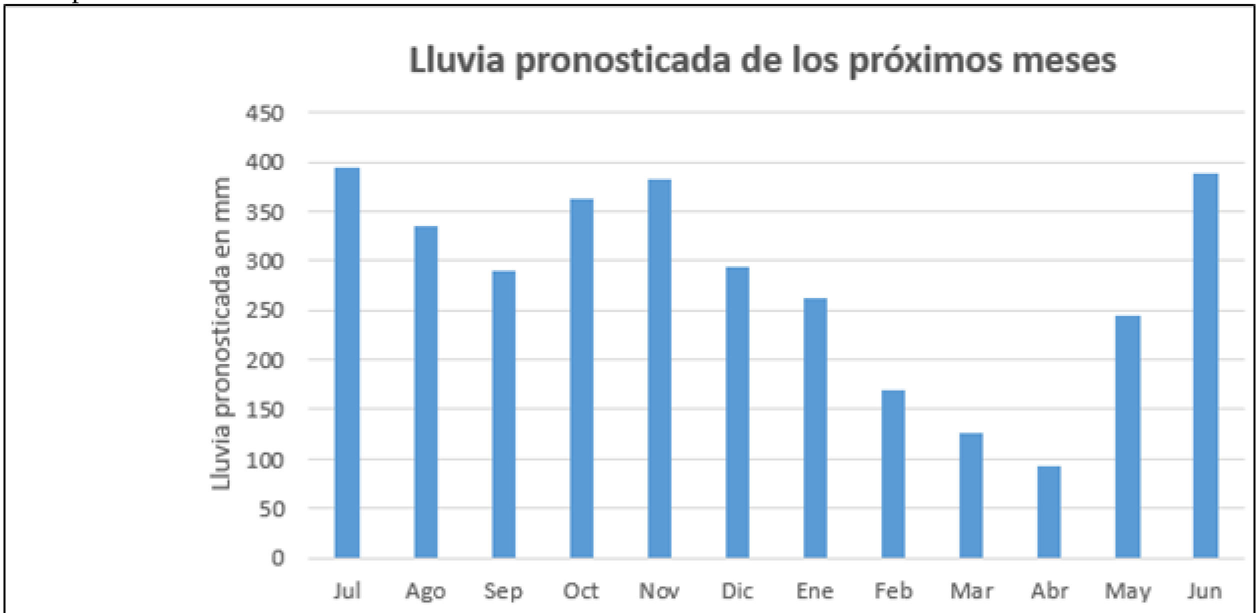
Example: Forecast for 12 months.



	Jul	Ago	Sep	Oct	Nov	Dic	Ene	Feb	Mar	Abr	May	Jun
Lluvia Pronosticada	394.3	334.7	290.2	363.3	381.8	293.1	261.8	168.9	126.5	93.5	244.8	388.2
% desviación del promedio	-10%	-20%	-25%	-15%	0%	-20%	0%	0%	0%	-10%	-15%	0%

28. According to this forecast, which month will have the largest amount of forecasted rainfall?

- ❍ Abr (1)
- ❍ Dic (2)
- ❍ Oct (3)
- ❍ Jul (4)

29. According to this forecast, which month is forecasted to be the most different from the average?

- ❍ Sep (1)
- ❍ Dic (2)
- ❍ Ene (3)
- ❍ Mar (4)

30. According to this forecast, which month will have the least amount of forecasted rainfall?
- ❍ Abr (1)
- ❍ Ene (2)
- ❍ Jun (3)
- ❍ Ago (4)

31. Please indicate what accuracy you would assign to this type of forecast in general on the scale from 1 (not accurate at all) to 5 (perfectly accurate):
- ❍ 1 (1)
- ❍ 2 (2)
- ❍ 3 (3)
- ❍ 4 (4)
- ❍ 5 (5)
- ❍ I don't know (6)

32. In one sentence, please explain why you gave this rating:

33. Please indicate if this type of forecast seems useful to you in managing water resources on a scale from 1 (not useful at all) to 5 (very useful)
- ❍ 1 (1)
- ❍ 2 (2)
- ❍ 3 (3)
- ❍ 4 (4)
- ❍ 5 (5)
- ❍ I don't know (6)

34. In one sentence, please explain why you gave this rating:

35. Please indicate if you would use this type of forecast for managing water resources on a scale from 1 (never) to 5 (always)
- ❍ 1 (1)
- ❍ 2 (2)
- ❍ 3 (3)
- ❍ 4 (4)
- ❍ 5 (5)
- ❍ I don't know (6)

36. Now consider the situation in which the forecast that they give later contradicts (does not match) the reality. Please indicate what accuracy you would give to this type of forecast in general on a scale from 1 (not accurate at all) to 5 (perfectly accurate):
- ❍ 1 (1)
- ❍ 2 (2)
- ❍ 3 (3)
- ❍ 4 (4)
- ❍ 5 (5)
- ❍ I don't know (6)

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37. Next, we would like to know about your access to the forecast information. Please indicate your agreement with the following statements:

	Strongly disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly agree (5)	I don't know (6)
I know where to get forecast information (1)	❍	❍	❍	❍	❍	❍
I can get forecast information when I need it (2)	❍	❍	❍	❍	❍	❍

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38. Different types of people or institutions make forecasts. Next, we would like to know how much you trust in the people or institutions that make forecasts. Please indicate your agreement with the following statements:

	Strongly disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly agree (5)	I don't know (6)
I trust the government agencies (1)	❍	❍	❍	❍	❍	❍
I trust the unviersities (2)	❍	❍	❍	❍	❍	❍
I trust in the private businesses (3)	❍	❍	❍	❍	❍	❍
I trust the people that use traditional methods (eg las pintas) (4)	❍	❍	❍	❍	❍	❍
I trust my family and friends (5)	❍	❍	❍	❍	❍	❍

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39. Now, we ask about the responsibility related to water. Please indicate your agreement with the following statements:

	Strongly disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly agree (5)	I don't know (6)
I need to use forecast information for my job (1)	❍	❍	❍	❍	❍	❍
I consult other people in my community or workplace when I take actions to manage water resources (2)	❍	❍	❍	❍	❍	❍
I have the responsibility to manage water resources (3)	❍	❍	❍	❍	❍	❍
Other people have the responsibility to manage water resources (4)	❍	❍	❍	❍	❍	❍

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40. Next, we would like to ask about your perception of the risk of not having enough water. Please indicate your agreement with the following statements:

	Strongly disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly agree (5)	I don't know (6)
There is enough water each time I need it to satisfy my needs. (1)	❍	❍	❍	❍	❍	❍
There will be enough water each time I need it to satisfy my needs in the next year(2)	❍	❍	❍	❍	❍	❍
There will be enough water each time I need it to satisfy my needs in the next 5 years (3)	❍	❍	❍	❍	❍	❍
Knowing that there will be enough water to satisfy my needs makes me feel safe. (4)	❍	❍	❍	❍	❍	❍

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41. We would also like to know if you have the resources to be able to manage water resources. These resources could be **Economic and Physical** (money, land, or equipment and supplies), **Organizational** (labor, political connections, cooperative involvement), or **Informational** (personal know-how, scientific information, forecasts). Again, please rate your agreement with the following statements:

	Strongly disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly agree (5)	I don't know (6)
I have available the economic and physical resources that I need to manage water resources(1)	❍	❍	❍	❍	❍	❍
I have available the organizational resources that I need to manage water resources (2)	❍	❍	❍	❍	❍	❍
I have available the information resources that I need to manage water resources (3)	❍	❍	❍	❍	❍	❍

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42. We would like to know about changes in your plans. Please indicate your agreement with the following statements:

	Strongly disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly agree (5)	I don't know (6)
I generally consider changes to be a negative thing. (1)	❍	❍	❍	❍	❍	❍
I'll take a routine day over a full day of unexpected events any time. (2)	❍	❍	❍	❍	❍	❍
I like to do the same old things rather than try new and different ones. (3)	❍	❍	❍	❍	❍	❍
Whenever my life forms a stable routine, I look for ways to change it. (4)	❍	❍	❍	❍	❍	❍
I'd rather be bored than surprised. (5)	❍	❍	❍	❍	❍	❍
If I were to be informed that there is going to be a significant change regarding the way things are done at school, I would probably feel stressed. (6)	❍	❍	❍	❍	❍	❍
When I am informed of a change of plans, I tense up a bit. (7)	❍	❍	❍	❍	❍	❍
When things don't go according to plans, it stresses me out. (8)	❍	❍	❍	❍	❍	❍
If one of my professors changed the grading criteria, it would probably make me feel uncomfortable even if I thought I'd do just as well without having to do any extra work. (9)	❍	❍	❍	❍	❍	❍
Changing plans seems like a real hassle to me. (10)	❍	❍	❍	❍	❍	❍
Often, I feel a bit uncomfortable even about changes that may potentially improve my life. (11)	❍	❍	❍	❍	❍	❍
When someone pressures me to change something, I tend to resist it even if I think the change may ultimately benefit me. (12)	❍	❍	❍	❍	❍	❍
I sometimes find myself avoiding changes that I know will be good for me. (13)	❍	❍	❍	❍	❍	❍
I often change my mind. (14)	❍	❍	❍	❍	❍	❍
I don't change my mind easily. (15)	❍	❍	❍	❍	❍	❍
Once I've come to a conclusion, I'm not likely to change my mind. (16)	❍	❍	❍	❍	❍	❍
My views are very consistent over time. (17)	❍	❍	❍	❍	❍	❍

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43. We would also like to know how you think about your relationship with the environment. Please indicate your agreement with the following statements:

	Strongly disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly agree (5)	I don't know (6)
It is important to protect nature so we can have clean air and water (1)	❍	❍	❍	❍	❍	❍
Humans have a responsibility to account for our own impacts to the environment because they can harm other people (2)	❍	❍	❍	❍	❍	❍
I have strong feelings about nature (including all plants, animals, the land, etc); these views are part of who I am and how I live my life (3)	❍	❍	❍	❍	❍	❍
The use of natural resources is necessary for countries to develop (4)	❍	❍	❍	❍	❍	❍
Technological solutions are sufficient to address many of our environmental concerns (5)	❍	❍	❍	❍	❍	❍

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We also want to know about your religious beliefs and practices:

44. My religious beliefs are what really lie behind my whole approach to life.

❍ Strongly disagree (1)
❍ Disagree (2)
❍ Neutral (3)
❍ Agree (4)
❍ Strongly Agree (5)
❍ I don't know (6)

45. How often do you spend time in private religious activities, such as prayer, meditation, or religious reading.
- ❍ More than once a week (1)
- ❍ Once a week (2)
- ❍ A few times a month(3)
- ❍ A few times a year(4)
- ❍ Once a year or less (5)
- ❍ Never (6)

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46. What is your gender?
- ❍ Male (1)
- ❍ Female(2)

47. How old are you?
- ❍ 18-34 (1)
- ❍ 35-49 (2)
- ❍ 50-64 (3)
- ❍ 65+ (4)

48. What is your education level?
- ❍ Northing (1)
- ❍ Elementary school(2)
- ❍ High school (3)
- ❍ Some university (4)
- ❍ Associates or Bachelors Degree (5)
- ❍ Masters Degree (6)
- ❍ PhD (7)

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49. In which sector do you work?
- ❑ Agriculture(1)
- ❑ Energy (2)
- ❑ Domestic(3)
- ❑ Government (4)
- ❑ Tourism(5)
- ❑ Education (6)
- ❑ Student (7)
- ❑ ASADA (8)
- ❑ NGO (9)
- ❑ Retired (10)
- ❑ Private business (11)

50. ¿What is your official position?

51.¿Where do you work?

52. How long have you worked there?
- ❍ <5 years
- ❍ 5 - 10 years(2)
- ❍ 10+ years(3)

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53. ¿Where do you live?

54. ¿How long have you lived there?
- ❍ < 5 years (2)
- ❍ 5 - 10 years (3)
- ❍ 10+ years (4)
- ❍ All my life (1)

55. ¿What is your monthly income in colones?

56.¿Do you have children or grandchildren?
- ❑ Children(1)
- ❑ Grandchildren (2)
- ❑ No (3)

57. ¿Are you a part of social organizations ¿Which?

Appendix E: Additional factor analysis results and descriptive statistics for Study 2

Table E.1: Results of factor analysis on ability variables. Factor loadings shown for each variable (N = 87).

Participants were asked to indicate their agreement with the following statements:	Factors	
	A1	**R1**
Factor A1: Access forecasts		
I know where to obtain forecast information.	0.88	
I can obtain forecast information when I need to.	0.87	
Factor R1: Availability of resources		
I have available the economic/physical resources I need to manage water resources.		0.62
I have available the organizational resources I need to manage water resources.		0.71
I have available the informational resources I need to manage water resources.		0.71
% of total variance explained	32%	29%
Cronbach's alpha	0.86	0.71

Table E.2: Results of factor analysis on variables related to the need to use forecasts. Factor loadings shown for each variable (N = 87).

Participants were asked to indicate their agreement with the following statements:	Factor
	S1
Factor S1: Feeling of water security	
There is enough water when I need it currently.	0.78
There will be enough water when I need it in the next year.	0.85
There will be enough water when I need it in the next 5 years.	0.75
Knowing I have enough water makes me feel secure.	0.63
% of total variance explained	33%
Cronbach’s alpha	0.79

Table E.3: Results of factor analysis on the accuracy, usefulness, and intention to use example forecasts. Factor loadings shown for each variable (N = 87).

Ratings for accuracy, usefulness, and intention to use made on 1 to 5 Likert-type scales.	Factors	
	STU1	**LTU1**
Factor STU1: Usefulness of Short-Term		
4-day forecast accuracy	0.487	
4-day forecast usefulness	0.727	
Intent to use 4-day forecast	0.856	
Factor LTU1: Usefulness of Long-Term		
3-month forecast accuracy		0.648
3-month forecast usefulness		0.820
Intent to use 3-month forecast		0.768
12-month forecast accuracy		0.659
12-month forecast usefulness		0.772
Intent to use 12-month forecast		0.723
% of total variance explained	0.173	0.363
Cronbach's alpha	0.695	0.866

Table E.4 Descriptive statistics for independent variables used in logistic regression analysis.

Variable	n	Min	Max	Median	Mean	SD
Understanding score	85	0.11	1.00	0.67	0.65	0.20
Perceived Forecast Usefulness						
Short-term forecast usefulness (Scores from factor STU1)	54	-2.15	2.07	-0.12	-0.09	0.80
Long-term forecast usefulness (Scores from factor LTU1)	54	-2.22	1.74	0.07	0.07	0.90
Perceived Need to Use Forecasts						
Mandated to use	63	1.00	5.00	4.00	4.02	1.06
Consult with others	62	1.00	5.00	4.00	3.47	1.10
Responsible for managing water resources	65	1.00	5.00	4.00	4.15	0.96
Feeling of water security (Scores from factor S1)	49	-1.81	1.94	-0.58	-0.26	0.97
Perceived Ability to Use Forecasts						
Access to forecasts (Scores from factor A1)	66	-3.45	1.44	0.02	0.01	1.00
Availability of resources (Scores from factor R1)	66	-2.38	2.30	-0.02	0.02	0.97
Trust in forecasts						
Traditional informal forecasts (Scores from factor T1)	65	-2.15	1.96	0.05	-0.01	0.99
Scientific formal forecasts (Scores from factor T2)	65	-2.91	1.65	-0.01	-0.04	1.04
Individual difference measures						
Resistance to change	82	1.00	4.00	3.00	2.55	0.79
Religiosity	81	1.00	5.00	4.00	3.60	1.09
Log(Income) (colones, ex.rate = 530 colones/1 USD)	41	11.51	15.20	13.53	13.44	0.92
Information sources (count)	78	1.00	7.00	3.00	4.00	2.00
Demographics						
Graduated college (1=yes, 0=no)	84	0(41.7%)	1(58.3%)	n/a	n/a	n/a
Government agency representative (1=yes, 0=no)	87	0(41.4%)	1(58.6%)	n/a	n/a	n/a
Provider (1 = yes, 0 = no)	87	0(50.6%)	1(49.4%)	n/a	n/a	n/a

Appendix F: Interview Protocol for Study 3

Introduction

Hello, my name is Matthew Babcock and I am a student from Carnegie Mellon University. As part of a scientific study, we are interested in knowing about your work with and opinions of One Montana's Resilient Montana project. We are interested in your thoughts, opinions, and experiences. There are no correct or incorrect answers.

This interview is completely voluntary and confidential. I would like to record the interview, so that I don't have to take notes and instead can focus on what you are saying. Any names or identifiable information mentioned during the course of our conversation will be coded and made anonymous in any transcripts. If you feel uncomfortable answering any question, let me know and we can skip that question and go on to the next one.

The interview will take approximately 45-60 minutes. You must be at least 18 years old in order to participate. No monetary compensation will be provided for your participation.

Do you have any questions before we start?

I will be starting the recorder now. Is that okay with you?

Part I: One Montana/Resilient Montana

1. Can you please tell me about the Resilient Montana project?
    a. In your opinion, what are the objectives of the Resilient Montana project? If there are more than one, what is the most important objective?
    b. How have these objectives changed over time?
    c. Can you explain how Resilient Montana tries to achieve its goals? What strategies does it use?
    d. How have these methods changed over time?
    e. How does Resilient Montana measure success?

2. Can you please describe what your role is in the project?
    a. What is your professional and educational background?
    b. How did you first become involved?
    c. When did you first become involved?
    d. What percentage of your time do you spend on Resilient Montana related work?
    e. How has your role and/or level of involvement changed over the time you have been a part of the project?
    f. What similar activities outside of Resilient Montana are you involved in?

3. Please list who you work with and/or have contact with related to the Resilient Montana project? And here is a list of people: could you please indicate which you work with in relation to Resilient Montana? For each of the people you indicated could you answer the following:
    a. With what frequency do you interact with this individual…

        i. …on the Resilient Montana project

    Scale:: 1: Never – 2: Yearly – 3: Monthly – 4: Daily – 5: More than once a day

ii. …on other work

Scale:: 1: Never – 2: Yearly – 3: Monthly – 4: Daily – 5: More than once a day

b. When did you start working with this individual? Did you work with this individual prior to the Resilient Montana project?

c. Can you describe how the frequency of interaction changed over the course of the project?

d. What is the nature of your interaction with this individual within the context of Resilient Montana?

e. What is the nature of your interaction with this individual outside of the context of Resilient Montana if there is one?

Part II: Montana's Climate, Impacts, and Ranchers

1. To the best of your understanding, can you please describe Montana's present climate?
   a. Has there been a change in the climate and/or water resources in the last 1-2 decades?
   b. How do you expect the climate or the state of water resources may change in the future?

2. Why is it important for ranchers to know about climate science and its effects on water availability? How are they affected?

3. What specific concepts do you think ranchers need to understand about climate science and its effects on water availability? Why?

4. What specific actions do you think ranchers need to take to respond to changing climate? Why?

Part III: Opinions on Successful Science Communication

1. Can you please describe how you have had success at communicating climate, water availability, or adaptation information to others? Do you have any examples where you have been unsuccessful?

2. Can you please describe what leads to successful communication as opposed to failure?

   a. Specifically what about the message leads to success?
   b. Specifically what about the messenger or the relationship leads to success?
   c. Specifically what about the information itself leads to success?

3. Can you think of specific challenges, opportunities, and strategies related to communicating climate, water availability, and adaptation information with ranchers in Montana?

4. Can you describe how communication of climate information and adaptation occurs with ranchers in Montana inside of the Resilient Montana framework?

5. Do you ever work directly with ranchers? In what way? What is that relationship like? Where you involved in communicating climate, water availability, and adaptation information to ranchers beforehand? In what way?

Part III: Demographics

1. What is your age?
2. Where do you live? For how long have you lived there? Are you from Montana originally?
3. Where do you fall on the following political spectrum? (Conservative to Progressive, Anti-Establishment to Establishment)

Appendix G: Interview participant quotes regarding societal divides.

"how do you get rural and urban seeing themselves as more connected than divided? Rural sees urban as where their professional services are and where their markets are, and urban sees rural as where they get their food, their energy, where they put their waste, where they recreate, so on and so forth. There are these basic ties." **Participant "62"**

"Rather than just have all perceptions of us versus them, and I'm not going (to the meeting). Because there will be a loser, and you know who's going to lose… Ag won't win." **Participant "66"**

"I don't think urban understands the need to build the bridge. We, in rural, because we feel the constant threat against our stuff, by urban. We know we need to build a bridge. Because our voices are few, and our well, our loss could be huge. And urban, I don't think they know about rural at all." **Participant "84"**

"yeah, there is no question because when you know when your plow is a pencil and you are two thousand miles from the field, farming looks easy" **Participant "83"**

"But people in the room saying how do I get more of this (information) and someone there was talking about 'well we need to develop', or 'we're working on it' was very, and I, don't take this the wrong way but, people in academia sometimes talking to people who are producers, there is a disconnect there. Because, the one group lives and dies year to year and the other group tends to have a little longer timeline to produce results on." ***Participant "73"***

"So you have this huge cultural gap and communication. And I think that happens a lot with environmentalists versus land owners. Environmentalists you know make a lot of their decisions with what I call a 'windshield survey' – you know they're driving around and they see something that doesn't look right so they comment on it without ever going to talk to the landowner" **Participant "83"**

Appendix H: Survey Protocol for Study 3

My name is Matt Babcock and I am a student researcher at Carnegie Mellon University. As part of a scientific study, we are interested in your opinions and experiences related to workshops such as the one you are participating in. This survey is completely voluntary and confidential. **PLEASE DO NOT WRITE YOUR NAME ON THE SURVEY.** We are interested only in your opinions, thoughts, and experiences, and therefore there are no right or wrong answers. If you do not want to answer a question, you can skip it. You need to be at least 18 years old to participate. The survey should take approximately 10 minutes of your time. Thanks!

Views on the workshop

1. How did you hear about this specific workshop? (circle all that apply)

   MSGA Agenda   Other Ranchers   Extension   One Montana   Other (please specify) ___________________

2. Did you know any of the presenters/organizers of the workshop before today? **Yes** or **No**
   If yes, who?
   ____

3. Did you know any of the other ranchers at the workshop before today? **Yes** or **No**
   If yes, about how many other ranchers? _____

4. In one or two sentences, can you describe why you decided to come to the workshop and what you hoped to get out of it?
   ____
   ____
   ____

For the next set of questions, please indicate your agreement with following statements where 1="completely disagree" and 5="completely agree" or "Not sure/I don't know."

5. The workshop met my expectations.

Completely disagree				Completely agree	Not sure/I don't know
1	2	3	4	5	6

   In 1 or 2 sentences, please explain your rating.
   ____
   ____

6. I will attend similar workshops in the future.

Completely disagree				Completely agree	Not sure/I don't know
1	2	3	4	5	6

7. The presentations at the beginning were informative.

Completely disagree				Completely agree	Not sure/I don't know
1	2	3	4	5	6

If they were, then in 1 or 2 sentences please describe what was informative.

____
____
____

8. Which of the presentations was most informative for you? (Please rank from 1 – most informative to 4 – least informative, or put 0 if not applicable)

   Montana Climate Office __ USDA __ Extension __ Montana Climate Assessment __

Please rate your agreement with the following statements where 1="completely disagree" and 5="completely agree" or "Not sure/I don' t know."

9. I will share information from this workshop with other ranchers.

Completely disagree				Completely agree	Not sure/I don't know
1	2	3	4	5	6

10. Changes in weather patterns have affected my ranching operations.

Completely disagree				Completely agree	Not sure/I don't know
1	2	3	4	5	6

If they have, then in 1 or 2 sentences please tell me how so.

____
____
____

11. Changes in **future** weather patterns will affect my ranching operations.

Completely disagree				Completely agree	Not sure/I don't know
1	2	3	4	5	6

If they will, then in 1 or 2 sentences please tell me they how will.

____
____
____

12. I have discussed strategies for dealing with changing weather patterns before this workshop.

Completely disagree				Completely agree	Not sure/I don't know
1	2	3	4	5	6

With whom did you discuss these strategies? (circle all that apply)
1 Workshop presenter(s) 2 One Montana 3 Other workshop participant 4 Other________________

13. I will seek out more information about changing weather patterns in the future.

Completely disagree				Completely agree	Not sure/I don't know

1	2	3	4	5	6

From whom will you seek out more information if you have relevant questions? (circle all that apply)
1 Workshop presenter(s)   2 One Montana   3 Other workshop participant   4 Other________________

14. I will seek out more information about ***dealing*** with changing weather patterns in the future.

Completely disagree				Completely agree	Not sure/I don't know
1	2	3	4	5	6

From whom will you seek out more information if you have relevant questions? (circle all that apply)
1 Workshop presenter(s)   2 One Montana   3 Other workshop participant   4 Other________________

<u>Views on breakout sessions</u>

15. Which breakout session did you participate in?   **Mesonet** or **Variable Stocking Rate (VSR)**
16. My breakout session was informative.

Completely disagree				Completely agree	Not sure/I don't know
1	2	3	4	5	6

If it was, then in 1 or 2 sentences please describe what was informative.
____
____
____

17. I will implement what I learned from the session on my ranch.

Completely disagree				Completely agree	Not sure/I don't know
1	2	3	4	5	6

18. Other ranchers will implement what they learned about from the session on their ranches.

Completely disagree				Completely agree	Not sure/I don't know
1	2	3	4	5	6

19. What would be the biggest reason for not implementing the strategy you learned about from the workshop on your ranch?

1 No need for the strategy   2 Lack of resources/cost   3 Lack of know-how   4 Other ____________________

20. Are there other strategies that you would like to see presented at future workshops? **Yes** or **No**
If yes, which strategies? ____

<u>Questions about you</u>

21. Is your primary occupation ranching? **Yes** or **No**   If no, what is? ______________________
22. What zip code is your ranch in? ________________
23. How many years have you been involved in ranching? __________________

24. Approximately how large in area is your ranch (acres)? ____________________
25. In what year were you born? ____________________
26. What level of formal education do you have? (choose the highest level)
    ○ Less than HS ○ High school ○ Some college ○ Associates Degree ○ BS/BA ○ MS/MA ○ PhD/MD/JD
27. How do you identify yourself politically on **social** issues?
    1 – very conservative 2 – conservative 3 – moderate 4 - liberal 5 – very liberal 6 – not sure
28. How do you identify yourself politically on **economic** issues?
    1 – very conservative 2 – conservative 3 – moderate 4 - liberal 5 – very liberal 6 – not sure
29. Are you originally from Montana? **Yes** or **No** If yes, which county? _____________________

If you have any questions about this survey or the research project in general, please contact Matt Babcock at mbabcock@andrew.cmu.edu. We appreciate your help and thank you for your participation.

If you are willing to help us learn more about ranching in Montana and about how these workshops are or are not helpful for what you do through an interview or longer survey, please provide your email address and/or phone number here (this information will be removed from the rest of the survey so your answers will remain anonymous):