Integrating Science and Policy: Climate Change Assessments and Water Resources Management

by

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Dedication

To my parents and Jonathan.

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List of Abbreviations

ADWR	Arizona Department of Water Resources
AISC	Arizona Interstate Stream Commission
AMA	Active Management Area
CAGRD	Central Arizona Groundwater Replenishment District
CAP	Central Arizona Project
CCSP	Climate Change Science Program
CGWA	Critical Groundwater Area
CIG	Climate Impacts Group
CISA	Carolinas Integrated Sciences and Assessment
CLIMAS	Climate Impacts for the Southwest
CWS	Community Water System
DWSRF	Drinking Water State Revolving Funds
EEA	European Environment Agency
ENSO	El Nino Southern Oscillation
EPA	Environmental Protection Agency
GIS	Geographic Information System
GMA	Groundwater Management Act
GWMA	Groundwater Management Area
IDWR	Idaho Water Resources Department
INA	Irrigation Non-Expansion Area
IPCC	Intergovernmental Panel on Climate Change
IQ	Interview Question
IRI	International Research Institute for Climate Prediction
ISC	Interstate Stream Commission
ISCP	Interstate Stream Commission Program

IWRB	Idaho Water Resources Board
MAF	Million Acre-Feet
NAPAP	National Acid Precipitation Assessment Program
NEPA	National Environmental Policy Act
NMOSE	New Mexico Office of the State Engineer
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
OGP	Office of Global Programs
OTA	Office of Technology Assessment
OSE	Office of the State Engineer
OWRC	Oregon Water Resources Commission
OWRD	Oregon Water Resources Department
PDO	Pacific Decadal Oscillation
PI	Principle Investigator
PM	Program Manager
PNW	Pacific Northwest
RISA	Regional Integrated Sciences and Assessment
ROD	Record of Decision
SBSTA	Subsidiary Body for Scientific and Technological Advice
SCO	Southwest Climate Outlook
SECC	Southeast Climate Consortium
SQ	Survey Question
SW	Southwest
USNA	United States National Assessment
USPBP	Upper San Pedro Basin Partnership
WADE	Washington Department of Ecology
WMCP	Water Management Conservation Plan
WRAP	Water Resource Allocation Program
WSCI	Water Supply and Conservation Initiative\
WWA	Western Water Assessment

Chapter 1

Introduction

Water resources availability depends upon the climate-driven global water cycle and society's ability to effectively manage water resources for human and environmental needs (NRC 2010a). Prolonged droughts that occur through natural climatic variability strain society's ability to manage water resources amongst competing demands for water withdrawals (e.g., to support population and economic growth and energy and agricultural production) and increasing pressure to reserve water for instream uses (e.g., ecosystem health, aesthetic and recreation purposes, and endangered species protections). Climate change impacts such as more precipitation falling as rain than snow, earlier snowmelt and runoff, reductions in groundwater recharge rates, longer and more severe droughts, more heavy precipitation events, increased evaporation, and sea level rise pose additional challenges for water resource managers (NRC 2010b; USGCRP 2009). Water managers' ability to respond to these changes in the climate-driven global water cycle depends on "the magnitude and speed of the changes . . . and on the resilience of human and environmental systems" (NRC 2009, p. 21).

A key strategy to address these climate-driven water management challenges is to help water managers better understand and characterize climate-related risks and vulnerabilities to water resources. Science has made enormous inroads in understanding how climate variability and climate change effect water resources but uncertainties remain (NRC 2010a). While uncertainty persists this advancement in understanding offers the potential to enable water managers to make more informed operational, management, and planning decisions to proactively respond to climate-related risks. For example, information about historic climatic variability can be used to support decisions to invest in the construction of new reservoirs and aquifer storage and recovery systems and to bolster efforts to achieve more efficient use and conservation of available water resources (NRC 2010b). These actions can build resiliency and potentially reduce future losses. However, though the use information that helps characterize and inform responses to risks posed by climate variability is more common, reliance on information about past climatic variability and today's assumptions about future water supply and demand for water is increasingly seen as insufficient for long-term planning (Milly *et al.* 2008). Some water managers recognize the increased risks posed by climate change impacts and are already incorporating novel climate information into management and planning. For example, projections of anticipated sea level rise are informing the design and construction of new infrastructure such as the decision to construct Boston's Deer Island Wastewater Treatment Plan at a higher elevation to accommodate rising sea levels (Adger *et al.* 2007). While examples of water managers' use of climate information is encouraging, increasing the use of climate information for water resources management and planning is critical to improve the robustness of decision making and build resilience to climate variability and change in the water sector.

The need to inform water resource decision making is especially acute in rapidly growing areas of the Southwest (SW) and Pacific Northwest (PNW) where climate variability—particularly drought—stresses already scarce supplies. Climate change induced alterations in the timing and availability of water may further stress the effective management of water resources in these regions. In light of these existing and anticipated water resource challenges, increasing the availability and utility of climate information for use by water managers in the PNW and SW is an important goal. However, simply increasing the supply of climate information does not ensure the information will be used.

Participatory research approaches that link information suppliers and information users are known to increase the development and use of information for decision making. For example, scientists at Regional Integrated Sciences and Assessments (RISAs) generate climate information using a stakeholder-driven approach aimed at producing useful information by working with potential information users, including water managers, to shape information products to better meet their needs. RISAs have been considered a success at translating science to policy because they address barriers to information use and enhance the drivers of information use including by facilitating effective two-way communication; co-producing user driven knowledge (Feldman *et al.* 2008; Lemos & Morehouse 2005; McNie 2008); being stable and long-term; producing credible, salient, and legitimate information; and, being perceived as "trusted" organizations (McNie 2008). For example, the Western Water Assessment's (WWA) work with local water managers in Colorado helped to overcome barriers to the use of tree ring reconstructions to enhance water supply planning (Rice *et al.* 2009). The co-production process involved WWA scientists and water managers working together to iteratively advance output from tree ring reconstructions and more seamlessly integrate with the water manager's existing water supply planning models.

This study focuses on the effort to co-produce knowledge and decision-making in the scope of two RISAs—the Climate Assessment for the Southwest (CLIMAS) in the SW and the Climate Impacts Group (CIG) in the PNW. Within these RISAs, scientists work with water managers to co-produce useful climate information. However, even with improvements in the supply of climate information for the PNW and the SW and despite growing risks posed by climatic changes, water managers in these regions have not universally employed climate information to enhance planning and management decision making. This slow adoption of information suggests that other factors beyond improved supply influence climate information use. This research seeks to fill this gap in our understanding of the dynamics between information production and adoption, especially exploring whether or not better climate information improves society's ability to manage water resources in light of climate related risks.

While researchers have begun to explore the use of RISA produced climate information through case studies (Rice *et al.* 2009; VanRheenen *et al.* 2003; Wiley & Palmer 2008; Wood *et al.* 1997), there has been relatively less effort in developing comprehensive, comparative, empirical studies of RISA information use. Moreover, most of this literature has explored the conditions and causes of the use of climate information, especially seasonal climate forecasting from a variety of information providers, including to a limited extent RISAs. Finally, most empirical studies in this area have focused on the process of information use rather than examining how this use may shape outcomes (i.e., in terms of better management of water, policies, etc.). Hence, what sets this dissertation work apart from previous efforts to understand climate information use is: (1) a comparative focus on information use by water managers and information production by two RISAs; (2) the stratification of the study sample of information users—RISA clients (defined as stakeholders who interact directly with a RISA) managing water resources at varying scales (e.g., local, regional, or state) and non-clients managing water resources at the local level—and non-users (see Table 1.1); and, (3) an investigation of outcomes focusing on the use of RISA information to aid in building resilience to climate variability and change.

Table 1.1 Stratification of study sample into client and non-client information users and non-users.

	RISA Clients		Non-clients	
Data Collection Method	Users	Non-users	Users	Non-users
Interviews with water managers (local, regional, and state)	✓	✓		
Surveys of water managers (local systems)			✓	✓

Examining two RISAs provided an opportunity for a better understanding of the benefits and constraints of the stakeholder-driven research model. It also allowed for better examination of information use and outcomes within and between regions and within and between groups of clients and non-clients. Furthermore, this research design permitted an empirical test of the effect of boundary management by comparing client users, client-non users, non-client users, and non-client non-users. Beyond testing boundary management, the large n study of non-clients coupled with the small n study of clients provided an opportunity to build upon and empirically test previously identified product, process, and context factors thought to shape information use and to identify new factors that condition information use. Lastly, a focus on outcomes (i.e., policies or actions that involve use of co-produced climate information) is used to empirically test the proposition that the stakeholder-driven research model contributes to improved societal outcomes (e.g., building resilience to climate variability and change).

1.1 Research Questions and Hypotheses

Specifically, this research aims to answer the following questions:

R1) Who uses RISA information and why do they use it and what differences, if any, exist between users and non-users of RISA information across regions and scales of decision making?

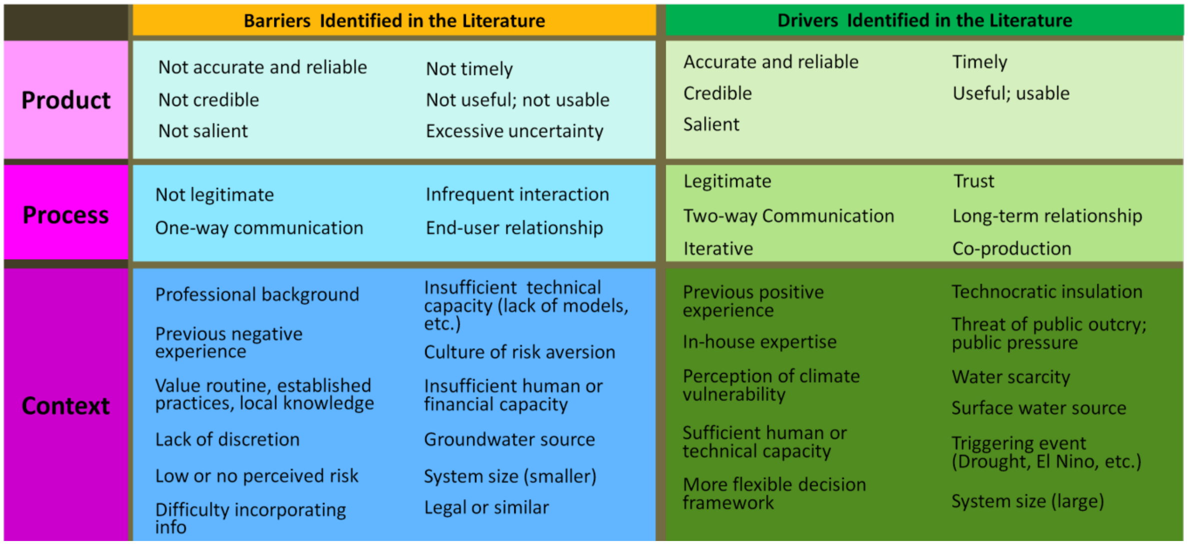
R2) What specific and measurable impacts do boundary management and the co-production processes have on information use? Boundary management describes the communication, interaction, and other boundary spanning efforts that bring scientists and potential information users together to help span the divide between the science and the decision- or policy-making spheres. Boundary work is thought to be critical to information use, but to date the effect of boundary management has been insufficiently tested.

R3) What societal benefit is derived from RISA information use by water managers?

   a. Does RISA information use increase the robustness of decision making at the local level and/or increase resilience to climate variability and change across decision making scales?
   b. How might RISAs contribute to effective knowledge-action systems for building resilience to climate variability and change in the water sector?

There is a robust literature examining factors affecting information use in the Pacific Northwest (Callahan *et al.* 1999; Pulwarty & Redmond 1997; Rayner *et al.* 2005; Snover *et al.* 2003) and the Southwest (Hartmann *et al.* 2001; Pagano *et al.* 2001), and in other parts of the U.S. (Lemos 2008; O'Connor *et al.* 2005; Rice 2009; Yarnal *et al.* 2006). Table 1.2 summarizes the barriers and drivers moderating information use identified in the literature.

Table 1.2 Factors that moderate information use identified in the literature



	Barriers Identified in the Literature		Drivers Identified in the Literature	
Product	Not accurate and reliable Not credible Not salient	Not timely Not useful; not usable Excessive uncertainty	Accurate and reliable Credible Salient	Timely Useful; usable
Process	Not legitimate One-way communication	Infrequent interaction End-user relationship	Legitimate Two-way Communication Iterative	Trust Long-term relationship Co-production
Context	Professional background Previous negative experience Value routine, established practices, local knowledge Lack of discretion Low or no perceived risk Difficulty incorporating info	Insufficient technical capacity (lack of models, etc.) Culture of risk aversion Insufficient human or financial capacity Groundwater source System size (smaller) Legal or similar	Previous positive experience In-house expertise Perception of climate vulnerability Sufficient human or technical capacity More flexible decision framework	Technocratic insulation Threat of public outcry; public pressure Water scarcity Surface water source Triggering event (Drought, El Nino, etc.) System size (large)

The first research question aims to contribute to this literature through the study of client and non-client RISA information users. Whereas information use among RISA clients is expected to be high given the focus on producing information that meets client needs, the rate of information uptake and use among non-clients is less certain. Furthermore, while some information is known about the characteristics (e.g., population served, water source) of RISA clients, less is known about the characteristics of non-client RISA users. However, a key hypothesis is that non-client RISA users and RISA clients who use RISA information will share key characteristics that drive information use. In other words, information use depends not just on the characteristics of the information supply side or the information itself (i.e. usable, timely) but also on characteristics of the information demand side including organizational characteristics of information users (i.e., clients and non-clients).

Comparing information use across regions should capture regional differences among clients and non-client information users and differences between RISAs. Differences are expected in spite of the common, stakeholder-driven approach because, by design, RISAs respond to place-based information needs and because available scientific expertise affects the scientific focus of the RISAs. Regional differences may also result from variation in water resource management challenges faced in the Southwest and Pacific Northwest that may impact regional demand and use of information use.

The second research question specifically focuses on improving our understanding of the relationship between boundary management and information use focusing on RISAs and their information users. RISAs are boundary organizations that employ a stakeholder-driven research approach that relies on boundary work to mitigate known product and process barriers to information use and to build upon known drivers of information use. This research empirically tests the RISAs as boundary organizations by analyzing known drivers (e.g., two-way communication) and barriers (e.g., one-way communication) that are essential aspects of boundary work. A second component of this research question aims at testing a component of a co-production of science and decision-making model—the Iterativity model proposed by Lemos and Morehouse (2005)—which describes a process whereby interaction, interdisciplinarity, and usable science produce improved innovation and societal outcomes. Specifically, this research empirically tests the effect of interaction through examination of RISA information use.

The third research question looks at the relationship between RISA information use and societal benefit. One outcome of interest is to examine whether the use of RISA produced climate information in management and planning increases the overall resilience of the water system to climate variability and change. The second aspect of the research question tests the hypothesis that RISAs contribute to effective knowledge-action systems that build resilience to climate variability and change. Knowledge-action systems as originally conceived by Cash *et al.* (2003) facilitate the translation of science into policy. Effective knowledge-action systems require communication, mediation, and translation of knowledge for use by policy makers (Cash *et al.* 2003). Because RISAs act to communicate, mediate, and translate climate information for water managers, RISAs may contribute to effective knowledge-action systems that increase the resilience of water systems to climate variability and change across regions and scales.

1.2 Intellectual Contribution

This research makes several important intellectual contributions. First, this effort provides a more comprehensive examination of the barriers and drivers of information use than has been attempted to date. This includes information use by RISA clients and non-clients spanning two regions and multiple decision making scales. Second, this research empirically and systematically tests the effectiveness of boundary management on information use across two regions. Third, this research goes beyond current case studies and their examination of RISA information use to comprehensively assess RISA information use by local, regional, and state water managers across five states and two regions. The goal here is not only to examine differences in use across decision environments but also to examine whether information use improves societal outcomes. One measure of societal outcomes is the increased resilience of water resources and systems to climate variability and change. Fourth, the analysis of information use and boundary work is taken together to explore and develop a framework for knowledge-action systems that build resilience in water resource management.

1.3 Format of Dissertation

The dissertation is organized into eight chapters. Chapter 2 presents background material focusing on a detailed description of the two RISAs, CIG and CLIMAS, and information about the structure of water policy and planning in each state (Washington, Oregon, Idaho, Arizona, and New Mexico). Parameters guiding the selection of CIG and CLIMAS for study are also detailed in this chapter. Next, chapter 3 provides an overview of the relevant literature including a discussion of boundary organizations, co-production, factors moderating information use, and knowledge-action systems. Chapter 4 describes and explains the research design including methods used for data collection and analysis. Chapters 5 and 6 are the main analytical chapters. Chapter 5 addresses the first two research questions while chapter 6 focuses on the third question. A discussion of survey and interview response rates, representativeness of respondents, and rates of RISA information use opens chapter 5. The bulk of the chapter presents results from the empirical test of barriers and drivers of information use and boundary management. The chapter closes with a discussion of the observed regional variation in the supply and use of climate information and a test of the iterativity model. Chapter 6 opens with a discussion resilience and knowledge-action systems. Results of the analysis of information use across scales of decision making are presented by region leading to a cross-region comparison. The chapter ends with a discussion of RISAs in the context of knowledge-action systems. Conclusions are summarized in chapter 7 as are suggestions for additional research. Recommendations based on the research findings are summarized in chapter 8 and focus on two main areas: strategies for increasing RISA information use and suggestions for improving knowledge-action systems that build resiliency to climate variability and change. Supplementary material is included in three appendices: the interview and survey protocols contained in Appendix 1, detailed calculations evaluating representativeness in Appendix 2, and results from the logistic regression in Appendix 3.

Chapter 2

Background

Managing water resources to meet increasing current and future demands from population and economic growth, agriculture, environmental uses, and energy production needs pose huge challenges for states, community water systems and water managers generally. These challenges are especially acute in rapid growing areas of the Southwest and Pacific Northwest where climate variability – particularly drought - stresses already scarce supplies. Climate change may further stress these regions by altering the: (1) timing and availability of water needed to satisfy increasing demands for water withdrawals and (2) the amount of water available for instream uses including for the production of hydropower and the protection of endangered species habitat. In addition to these stresses, the Pacific Northwest may also face sea level rise in coastal areas resulting from climate change.

Water availability is affected by climate variability and change as well as local constraints: the supply of and demand for water; the ability to store and retrieve water from natural and man-made surface and groundwater reservoirs; and, the quantity of water able to be stored in any given year. Because the amount of water available depends on the climate, climate information may assist state, county, and local water managers better plan and manage for drought and climate change. Scientists have improved the ability to forecast climate variability and have developed proxies of historical climate (e.g., tree ring reconstructions) to effectively extend our understanding of past climatic variability well beyond the limits of the instrumental record. More recently, climate scientists have developed global and regional scale climate models to better predict potential climate change impacts across spatial and temporal scales. However, for many years improvements in the supply of climate information did not translate into increasing use partly because scientists were not adept at understanding user needs for information and partly because potential users did not recognize the potential utility of this new information (CCSP 2008).

As scientists became more attuned to the needs of water managers and water managers began to see the potential for climate information use, other impediments to information use emerged. Research has illuminated these barriers to information use and informed the development of strategies to mitigate them. Similarly, better understanding of the factors that facilitate information use has informed activities meant to enhance the production and use of scientific information. Some of these enhancements, designed to overcome barriers to information use and to assist in the development and translation of climate information to the water sector, take the form of decision support experiments or boundary spanning organizations (CCSP 2008). Boundary organizations help bridge the divide between information producers and information users (Guston 2001; Jacobs *et al.* 2005) by enhancing and sustaining communication between scientists and water managers (McNie 2008; Sarewitz and Pielke 2007) and by translating information into more useful and usable forms. This translation component is particularly important in the case of climate information that is characterized by a high degree of uncertainty. Lastly, boundary organizations help facilitate the co-production of knowledge through collaboration between information producers and users (Lemos and Morehouse 2005; McNie 2008).

2.1 The RISA Program

Of interest here is a program known as the Regional Integrated Sciences and Assessments (RISA) established by the National Oceanic and Atmospheric Administration (NOAA). NOAA supports eleven RISA Programs to facilitate integrated and interdisciplinary, place-based research and assessment aimed at improving understanding of the interaction of climate, society, and the environment across difference spatial and temporal scales (Simpson 2009). The origins of the RISA program can be traced to the early 1990s when NOAA's Office of Global Programs (OGP) began funding human dimensions research (Pulwarty *et al.* 2009). That research yielded insights into the complex socioeconomic impacts of climate and informed the potential value of integrating social and physical sciences in support of decision making (NRC 2008). Because RISAs interact with stakeholders to produce useful and usable information that meets stakeholder needs, they are seen as boundary organizations (Lemos and Morehouse 2005; McNie 2008). RISAs produce climate information and develop "innovative outreach activities" that support the translation and use of that information to help manage climate variability and change at local, state and regional scales (Simpson 2009). Climate information includes but is not limited to paleoclimate data; means, extremes, and interpretation of instrumental climate data; seasonal climate forecasts; and, projections of global and regional climate change (Anderson *et al.* 2009).

The RISAs operate across the United States in eleven regions: Alaska, the Pacific Islands, the Pacific Northwest (i.e., Climate Impacts Group), California and Nevada (i.e., California Applications Program), the Southwest (i.e., Climate Impacts of the Southwest), the West (i.e., Western Water Assessment), the South (i.e., Southern Climate Impacts Planning Program), the Southeast (i.e., Southeastern Climate Consortium), the Carolinas, the Great Lakes and New England. The nine RISAs and their geographic focus are shown in Figure 2.1. The Great Lakes and New England RISAs are the newest RISAs funded during the most recent funding cycle. This latest cycle also precipitated a change in the Pacific Northwest as the Climate Impacts Group (CIG) was not renewed and instead RISA funding was awarded to Oregon State University (OSU) (personal communication, May 19, 2010). The additional RISAs are identified as "new sites" in Figure 2.1.

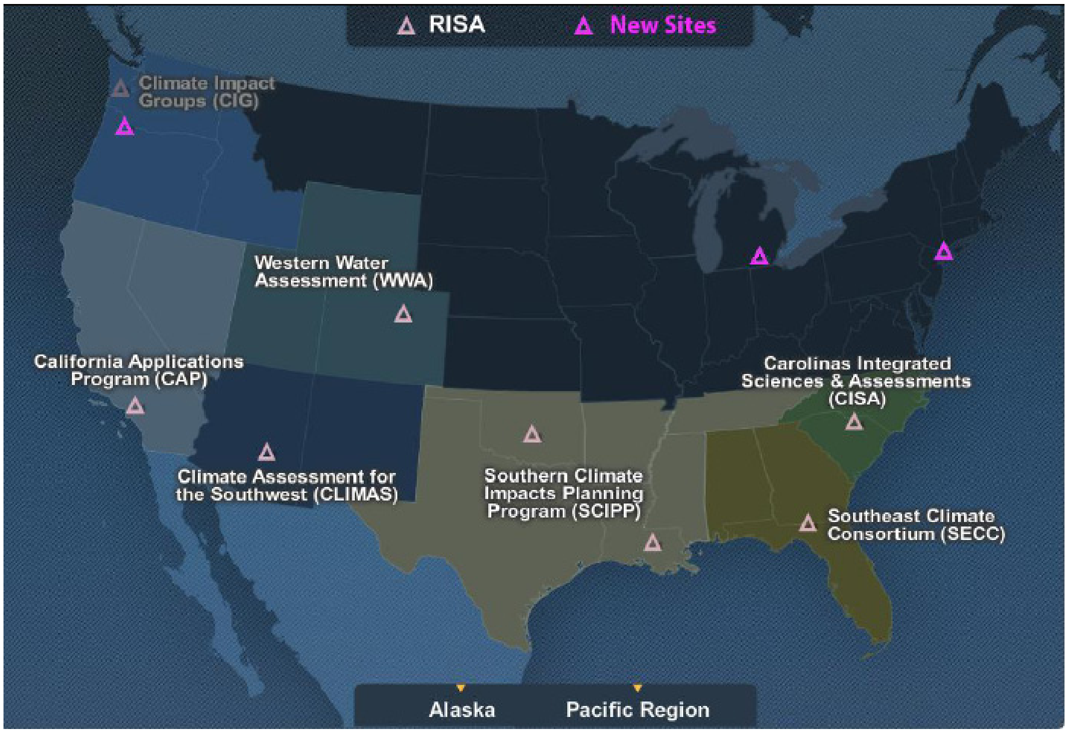


Figure 2.1 Regional Integrated Sciences and Assessments (Koblinksy 2010).

The RISA program began with CIG in 1995 initiated by: (1) NOAA's interest in funding experimental, place-based, human dimensions climate research; (2) a climate related focusing event in the Pacific Northwest; and, (3) the leadership of the Principal Investigator Edward Miles who recognized the need for regional climate assessments for the region (Miles 2008; Pulwarty *et al.* 2009). Miles (personal interview, June 4, 2008) felt strongly that global climate assessments like that produced by the Intergovernmental Panel on Climate Change (IPCC) could not offer the kinds of regionally or locally specific information necessary for decision makers to effectively manage climate variability and change. His IPCC experience, organizational and persuasive skills, and good timing precipitated the creation of CIG and launched NOAA's RISA program. Most RISA projects involve natural, physical, and social scientists working alongside regional and/or local clients to develop useful climate information that meets the needs of those clients. Early RISA information production efforts focused on climate variability and climate extremes but have expanded over time to include both climate variability and change applied to vulnerabilities at the regional to local context (Pulwarty *et al.* 2009).

While RISAs share common goals - to link climate observations, forecasts, and predictions with integrated vulnerability assessments to develop knowledge useful for regional and local decision makers, RISAs have their own regional identities (ISPE 2000; Pulwarty *et al.* 2009). RISAs developed along different paths according to: the scientific expertise marshaled within the particular RISA; the identification of critical local and regional issues, decision making needs and information gaps; and, the capacity for information use among potential clients. For example, the Carolinas RISA (CISA), established in 2003, initially worked extensively with clients involved in the Federal Energy Regulatory Commission dam relicensing process (CISA scientists, joint telephone interview, October 7, 2008). This work resulted in the development of a low flow protocol for hydropower dam operations (McNie *et al.* 2005). Since then, CISA has expanded to include drought monitoring and assessment, watershed modeling, and coastal climate extension (CISA 2007).[1] Since its inception, the Southeastern Climate Consortium (SECC) has focused on providing information to meet the needs of agricultural producers vulnerable to climate fluctuations and extremes (McNie *et al.* 2005). This work involves translating El Niño Southern Oscillation (ENSO) climate forecasts into information useful to improve farmer decision making (McNie *et al.* 2005). More recent efforts target potential information needs of municipal water providers (J. O'Brien, personal interview, May 19, 2008).

One of the major strengths of the RISA program is the ability to bridge climate assessments across time scales (e.g., ENSO, Pacific Decadal Oscillation, long-term climate change, etc.) and sectors (e.g., forests, wildfires, and water resources or endangered salmon, municipal water supply, and hydropower) to produce interdisciplinary science (Lemos and Morehouse 2005; Pulwarty *et al.* 2009). Another strength, and a key to their success, is their longevity and responsiveness to user needs (Anderson *et al.*, 2009). This longevity has enabled the RISA programs to develop and mature over time. This maturation process has facilitated creation of research programs that are decision-relevant and the creation and maintenance of dedicated user networks (Anderson *et al.*, 2009; Pulwarty *et al.* 2009). Sustained networks enable the

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[1] From http://www.cas.sc.edu/geog/research/cisa/highlights.html last updated 2007.

identification, development, and continued refinement of information that meets user needs further increasing the relevance of the RISAs (Anderson *et al.* 2009).

In addition to differing research foci, RISAs also vary in their research approach and stakeholder interaction. Some RISAs (e.g., the Pacific Islands RISA), predominately act as an information broker, that is, it focuses on creating and maintaining sustainable information networks to improve information dissemination rather than focusing on the production of new information (McNie *et al.* 2005; McNie 2008). However, most RISAs use a stakeholder-driven approach that includes research on both stakeholder information needs (demand for information) and the production of useful climate information (supply of information) to enhance stakeholder decision making (McNie *et al.* 2005; Sarewitz and Pielke 2007). This latter approach often involves both basic and applied research to support stakeholder decision making and to advance the state of the science. RISAs often employ multiple approaches from basic research to stakeholder-driven research to brokering of information depending on the supply of and demand for information.

2.2 RISA Selection for Study

Studying the RISA model in the context of water resources management is an important focus of this research. Fortunately, most RISAs have a significant focus on water resources because climate variability and change affect the hydrology of water resources and because water is fundamental to the sustainability of scoio-economic and ecological systems. The tailoring of water resources and climate research varies by region with some RISAs focusing on applications for municipal water supply, energy production, fisheries, agriculture, dam relicensing, drought planning and/or climate change adaptation or combination of these. My interest in understanding the use of climate information by municipal and state water managers in particular, narrowed the choice of RISA. Of the six RISAs with a substantial municipal water resources management focus, the Climate Impacts Group in the Pacific Northwest (CIG) and the Climate Impacts of the Southwest (CLIMAS) were selected for study for meeting four important criteria: (1) they were well-established; (2) they produced climate information for local, regional, and state water managers; (3) they were receptive to and facilitated access to their clients, and (4) the regions face critical water problems. Longevity of the RISA was an important consideration since established user networks and the level of maturity of the research program are critical to better meet user needs. Longevity of operation is beneficial because it means the RISAs have matured from the initial scientific team development, stakeholder network development, and pilot study phases and subsequent impacts studies phases (Pulwarty *et al.* 2009). These initial phases involve two lines of scientific inquiry. On the one hand, the RISAs assess the impact of multiple, interacting regional stresses resulting from climate variability and change and, on the other hand, RISAs identify client decision needs that might benefit from new climate information. This initial multi-year effort provides the important foundation for the RISAs but nonetheless is a test- or grounding phase. Choosing RISAs still in the network and research agenda development stages would preclude any substantive investigation into longer-term client information use and outcomes. RISAs that have operated a decade or more like CIG and CLIMAS have: established credibility in their respective regions; attracted and maintained a large and continually expanding network of clients with the capacity to use relevant climate science; and, iterated sufficiently with their clients to develop and produce useful information products (Pulwarty *et al.* 2009).

The second important factor for RISA selection was having a strong climate and water focus. CIG has a strong program looking at climate change applications for municipal and state level water management and an established program for climate variability. Recently, it has begun a paleoclimate research program. CLIMAS is more focused on climate variability than climate change, and has a strong program in paleoclimate research including applications for local water managers and state level drought planning.

The last two important factors considered in RISA selection were accessibility and the criticality of regional water issues. Accessibility was important in terms of gaining access to RISA clients and RISA scientists for data collection (i.e., interviews). Both CIG and CLIMAS graciously agreed to grant and facilitate access to their clients by providing contact information and by sanctioning those contacts. Also, RISA scientists generously gave their time to review protocols used in the data collection and to provide information about the history and conduct of the RISA. The criticality of water issues for the region was the last selection factor. Water issues are discussed in more detail later in the chapter but generally speaking both regions experience drought and other water resource stresses.

The next sections describe the location and structure of the RISAs, their philosophy and approach, and the type of information they provide for water managers at state, regional, county, and local levels. The information contained in the remainder of this chapter provides the basis for the examination of information use by water managers in the Pacific Northwest and Southwest described in the analysis chapters.

2.2.1 CIG

The Climate Impacts Group (CIG) is housed at the University of Washington in Seattle, Washington in a building just a block from Portage Bay, a waterway that feeds into the Puget Sound. The CIG team came together on July 1, 1995 in the lead up to the United States National Assessment of the Potential Consequences of Climate Variability and Change that officially began in 1997. Edward Miles, the Principal Investigator, participated in the Intergovernmental Panel on Climate Change's (IPCC) Second Assessment Report, Working Group 2 from 1993-1994. It was this experience with the IPCC that convinced him of the need to have better spatially resolved climate information for regional and local decision-makers. Dr. Miles spearheaded two unsuccessful efforts to secure funding for regional climate impacts research for the Pacific Northwest in 1993 and again in 1994. His efforts incorporated the idea of a watershed scale (i.e., the Columbia River Watershed), regional (i.e., the Pacific Northwest) focus for downscaling climate information (personal interview, June 4, 2008). The geographic focus is shown in Figure 2.2. Finally, a third proposal, focused on climate variability and change impacts in the Pacific Northwest a unique focus at the time, was successful and marked the beginning of CIG in 1995 (Snover and Miles 2008).

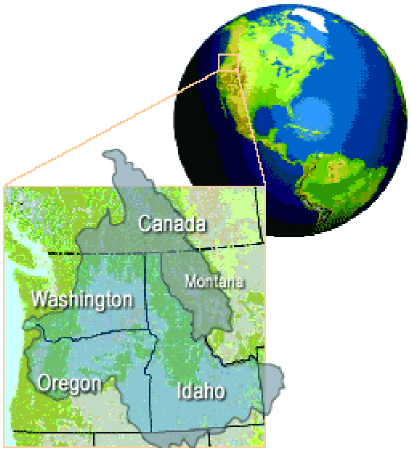

Figure 2.2 CIG Geographic focus.[2]

CIG's goal is to undertake basic research aimed at understanding climate impacts in the PNW and promoting application of this information in regional and local decision making.[3] Funding from NOAA's Office of Global Programs necessitated working with user communities to understand how to improve the utility of climate variability forecast information. The user community was initially defined as "decision makers relevant to formal natural resource management policy and managerial choices in the PNW" who "could potentially benefit from the use of climate information" (Snover and Miles 2008). These decision makers included "municipal, state, regional, tribal and federal agencies responsible for managing the region's water, forest, fishery, and coastal resources" (Snover and Miles 2008). CIG interviewed personnel from the agencies to understand how they might use climate information. These interviews informed CIG's engagement and outreach efforts including their focus on drought information, building capacity to use climate information, building awareness and understanding of climate variability, and information dissemination. The interviews also identified characteristics of user communities that make the region more vulnerable to climate variability and change impacts including: inflexibility, lack of capacity to respond to drought, and a fragmented management structure. The user community definition broadened over time from the early emphasis on public agency and tribal decision makers to include "city and state elected officials, the business community, and the public" (Snover and Miles 2008).

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[2] http://cses.washington.edu/cig/
[3] http://cses.washington.edu/cig/about/about.shtml

When CIG began in 1995, interest in climate variability and climate change in the Pacific Northwest was slight. Initially, CIG focused on climate variability in part because the political climate nationally and regionally in the late 1990s precluded a focus on climate change. The first stakeholder meeting took place in 1997 as part of the CIG led Pacific Northwest regional component of the United States National Assessment. That first meeting was sparsely attended attracting roughly 170 people (personal interview, June 4, 2008). However, interest in climate variability rapidly expanded with the onset of a strong El Niño event during 1997-1998 that focused public and stakeholder attention. Expertise at CIG facilitated pioneering work on climatological cycles like ENSO and, eventually, the Pacific Decadal Oscillation (PDO) (Mantua *et al.* 1997; Miles 2008). Early success brought more visibility and interest in CIG's research. By 2005 interest in climate information had risen dramatically and a second large regional meeting attracted over 800 people (Miles 2008).

Over time CIG has expanded its research focus to include both climate variability and change spanning four key, interconnected sectors in the Pacific Northwest: water resources, aquatic ecosystems, forests, and coasts and the human socioeconomic or political systems associated with each.[4] The focus on climate and water resources is a key strength due to the early focus on water and a number of breakthroughs like the identification of the PDO in 1997 (Mantua *et al.* 1997). Recent funding has further expanded the research focus to include agricultural impacts, infrastructure, public health, paleoclimate reconstructions of PNW streamflow, and climate change adaptation.

CIG's water resources sector work focuses on a number of key areas: developing better long-range streamflow forecasts for water management; projecting climate change impacts on regional water resources; and, developing methods to improve integration of climate information into water resources operation, planning, and management in the PNW.[5] This work is often integrative as, for example, evaluating the consequences of different water management approaches on hydropower production and salmon

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[4] http://cses.washington.edu/cig/ and http://cses.washington.edu/cig/about/about.shtml

[5] http://cses.washington.edu/cig/res/hwr/hwr.shtml

restoration efforts in the context of changing water demands and availability. An integral part of CIG's climate and water resources research is their annual climate and streamflow forecasting workshops, planning and policy workshops on climate change impacts, presentations, and other research consultancies.[6] The water workshops target local and regional decision makers and are held at various locations across the region every fall and spring. Each workshop is tailored to the particular regional location so that information is made relevant to regional attendees. CIG also sponsors occasional, high-profile climate change workshops aimed at upper level policy makers (Snover and Miles 2008).

2.2.2 CLIMAS

The Climate Assessment for the Southwest (CLIMAS), which began in 1998, is housed at the University of Arizona in Tucson, Arizona and is focused geographically on Arizona and New Mexico in the Southwestern United States. Unlike CIG, CLIMAS has seen a number of individuals assume the role of Principal Investigator over time. From its inception, the mission of CLIMAS was to "improve the ability of the region to respond sufficiently and appropriately to climatic events and climate changes" (Benequista *et al.* 1999). To fulfill this mission, CLIMAS brought together natural and social scientists studying climate processes and impacts in the Southwest with resource managers and decision makers who need climate information to improve decision making. Like other RISAs, CLIMAS was driven to produce climate information useful to regional decision makers and resource managers from the outset. The usefulness of this approach is recognized by clients:

> *"[CLIMAS is] not simply throwing climate science over the transom and hoping for the best...it's a more thoughtful, interactive approach to the communities that use your information…" (Ferguson 2009)*

Besides conducting stakeholder-driven research, CLIMAS also plays the role of an information broker "providing a conduit for information and facilitating the development of information networks" (Ferguson 2009; McNie *et al.* 2007).

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[6] http://cses.washington.edu/cig/res/hwr/hwr.shtml

The current Program Manager described the CLIMAS research philosophy as a bit of a "scattershot approach" reflecting their focus on being nimble and responsive to opportunities when client needs align with CLIMAS' scientific expertise (telephone interview, September 4, 2008; McNie *et al.* 2007). This philosophy and approach has resulted in an evolving array of research projects some of which were not anticipated in the initial program design (McNie *et al.* 2007). Early research focused on developing seasonal forecasts for urban water managers in Arizona including the cities of Phoenix, Tucson, Nogales, and the Benson-St. David area and for the ranching sector (Morehouse 1998). It also included modeling of monsoon dynamics, interpolation and downscaling of historical and paleoclimate data to fit local needs, and analyzing snowpack (Morehouse 1999). The development of extreme drought conditions in the Southwest in the late 1990s continuing into the early 2000s prompted a shift in focus to help stakeholders cope with the drought by providing up-to-date, comprehensive, climate information (Carter 2002). Over time, CLIMAS expanded into other areas including resource economics, air quality, fire management, and public health (McNie *et al.* 2007). For example, resource economics projects include research on the economics of water resources, range and livestock, and climate change impacts for the Southwest while public health research focuses on the role of climate variability and change on disease ecology (CLIMAS 2010; Haas 2006).

Research aimed at water managers initially focused on "evaluating the sensitivity of urban water systems to droughts of magnitudes comparable to the most severe one-, five-, and ten-year droughts in the historical record" (Morehouse 1999). Efforts directed at informing state level drought planning and monitoring continue as do other efforts to help water managers' cope with climate variability and change. CLIMAS has also undertaken extensive paleoclimate research on watersheds important to Arizona water managers and on water resource economics including such topics as water banks, water transfers, and instream flows (Haas 2006).

CLIMAS initially focused on establishing a stakeholder network, assessing information needs and gaps, and initiating research on "integrated natural, physical, and social science research initiatives to assess and enhance knowledge about regional climate variability, vulnerability, impacts, and responses" (Benequista *et al.* 1999). CLIMAS uses a number of different approaches to communicate and interact with potential information users and to disseminate information. These efforts include publishing a monthly climate outlook report for the southwest, the Southwest Climate Outlook, a semi-annual Newsletter describing research projects and activities, holding annual workshops, publishing peer-reviewed and other reports and articles, and other outreach. Researchers at CLIMAS also periodically conduct evaluations on their outreach activities and informational products to evaluate usability and to identify information needs.

2.3 The Regions: The Pacific Northwest and Southwest

Understanding how, why, and to what effect water managers in the Pacific Northwest and the Southwest use climate information is important. The Southwest seems like an obvious choice given the well-publicized rapid population and economic growth coupled with warnings of water scarcity and stress (Alcamo *et al.* 2000; Gleick 1990; Hurd *et al.* 1999). The PNW is a less obvious choice. The same studies that point with alarm at existing and potential increasing water scarcity in the Southwest leave the impression that the Pacific Northwest faces little water stress or vulnerability from climate variability or change (Alcamo *et al.* 2000; Gleick 1990; Hurd *et al.* 1999). However, upon closer examination both regions face keen water resource management challenges. For the Southwest, challenges arise from growth and scarcity but also from the heavy dependence on the Colorado River, pending water rights adjudications, interstate river compacts, and a nascent planning infrastructure. For the Pacific Northwest, scarcity arises from multiple competing uses (e.g., hydropower, instream flows, municipal supplies, agriculture) that squeeze a limited water supply particularly in the summer months when demand is highest and the ability to store water to bridge low flow years is limited. In both cases, climate change will further stress resource availability. Thus, there is critical need to understand the water resource management structure that exists in each region and the stressors in play including population and economic growth, climate variability, and climate change. This section outlines the water management structure in place by state for Washington, Idaho, and Oregon in the Pacific Northwest and for

Arizona and New Mexico in the Southwest. Management structure means the water management agencies tasked with management and planning for water resources at the state level and the legal framework for water allocation, adjudications, etc. Later in the analysis section, existing and potential stressors are described including an analysis of how the RISAs work with water managers at the state, regional, and local level to provide climate information to help mitigate identified stressors.

2.3.1 Pacific Northwest States

The state governor generally has a limited role in water resources policy and management at the local level though may play a larger role at the state or executive level. The governor may declare droughts and emergencies, form advisory bodies, enact new policies through executive order, etc. While the governor may influence statewide activities, the policymaking authority for state agencies and departments lies with the legislature and with the rule making functions of the state agencies whose authority is established by legislative action. The legislature and state agencies may also exert influence over local level water managers through new laws and rules.

2.3.1.1 Washington

State Agency

The state agency responsible for water resources management, planning and policymaking is the Washington Department of Ecology (WADE). Their mission is to "protect, preserve and enhance Washington's environment" and to promote the stewardship of "air, land and water for the benefit of current and future generations."[7] WADE also provides funds for water systems. Of all the state agencies included in this analysis, WADE clearly stood apart in the visibility and importance they gave to addressing climate change (telephone interview, May 22, 2009). On the department website WADE boldly states: "Washington State isn't waiting to see what happens with climate change. We're helping lead the way." However, the bold statement has not yet translated into practices that incorporate climate change into water resource management

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[7] http://www.ecy.wa.gov/about.html

and planning. The Washington Department of Health administers the state's drinking water program ensuring Public Water Systems meet the requirements of the Safe Drinking Water Act.

Legal Framework

As in other states, waters in Washington State belong to the public and individuals or groups must obtain a water right to be legally authorized to withdraw a defined quantity for a beneficial use (e.g., irrigation, domestic water supply, power generation, etc.).[8] In practice, new water rights are difficult to obtain as most surface and groundwater in the state is fully allocated. Any withdrawals commencing after the 1917 Surface Water Code or after the 1945 Ground Water Code require a permit. Water rights established prior to 1917 for surface water or 1945 for groundwater are vested rights. Most vested rights have been claimed under the 1967 Claims Registration Act, passed to record the amount and location of vested water rights.[9]

The 1945 Groundwater Code extends "the application of such surface water statutes to the appropriation and beneficial use of ground waters within the state" (Caldwell 1998). Prior to 1945, use of groundwater was unregulated. The Ground Water Code provided for the conjunctive management of groundwater and surface water to forestall undue impacts of groundwater withdrawals on surface water resources and to subjugate junior groundwater rights to the often more senior surface water rights. However, the law creates a class of exempt withdrawals of up to 5,000 gallons per day from permitting requirements. These exempt withdrawals include those for stockwatering, domestic purposes, watering a lawn or noncommercial garden up to one-half acre in area, or industrial uses (Caldwell 1998). Generally, these "exempt wells" are considered so small as to have no significant impact on groundwater quantity and quality. Unfortunately, as in Arizona, the cumulative impact of Washington's exempt wells creates havoc with water planning and with enforcing the doctrine of prior appropriation. In Washington as in Arizona, developers use the exemption loophole to develop property without obtaining

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[8] http://www.ecy.wa.gov/programs/wr/rights/water-right-home.html
[9] Ibid.

permitted water rights often because new water permits are not available or because using the exempt well provision is more cost effective. The proliferation of exempt wells makes managing water resources challenging because the amount of water withdrawn from these wells is not quantified (Caldwell 1998). Management is also challenged because these unregulated, unquantified groundwater withdrawals often affect highly regulated and often fully- or over-allocated streamflows hydraulically connected to groundwater aquifers (Caldwell 1998).

Fully implementing conjunctive management is also challenged in other ways. For example, lack of enforcement of prior appropriation rights is a major obstacle to efficient water allocation in Washington (Slaughter 2009). Another concern is the application of conjunctive management to maintain minimum instream flows. Some complain that applying conjunctive management in this case is too restrictive, essentially constraining withdrawals to such an extent that permits become worthless. Minier (1998) claims the problem arises because groundwater regulations condition groundwater permits on the maintenance of minimum instream flows if there is "significant hydraulic continuity" between the surface water and the proposed source of groundwater. However, because the regulations do not define "significant hydraulic continuity", Washington state courts have defined "significant" quite liberally such that essentially any hydraulic continuity is significant, regardless of the magnitude of the effect of groundwater withdrawal on the stream (Minier 1998). In some cases, this has led to the situation where a water right cannot be fulfilled due to the groundwater to surface water connection. In comparison, Arizona courts interpret hydraulic connectivity so restrictively that the definition does not protect surface water rights from junior (i.e., lower priority water rights holders) groundwater developers.

Planning

Washington State requires all new public water systems to develop long-range comprehensive water plans that include: water quality, water resources, source protection, reliability, financial viability, and conservation (Gregoire *et al.* 2000). The plans also include a water resource analysis and a water right assessment. The water resource and water right assessments consider water quantity to ensure sufficient resources are available and to plan for anticipated shortage conditions and the possibility of acquiring additional water rights. However, planning requirements do not expressly require consideration of climate change impacts on water supply reliability. Multiple planning authorities review the plans at a level of integration and communication that is rare for state mandated local water resource planning. The Public Water System Coordination Act of 1977 encourages local governments to consider regional water planning to encourage coordinated planning and development of water supply systems and to help preserve water resources (Gregoire *et al.* 2000).

In 1998, the Washington state legislature passed the Watershed Planning Act to provide a process whereby local citizens in a watershed could come together to jointly determine how to assess and manage water resources at the watershed level. The Act requires several key steps including undertaking an assessment of water supply and use; ensuring that sufficient instream flows are available long-term; and, planning for future out-of-stream uses. The Act also provided funding to these watershed groups to assist in planning. To date twenty-seven watershed planning units have formed and are currently implementing watershed plans (WADE 2009).

2.3.1.2 Oregon

State Agency

The State Legislature established the Office of the State Engineer in 1905 (OSSAD 2007). A separate agency, the Oregon Water Resource Board, was established in 1955 from the former Reclamation Commission but was eventually merged along with the Office of the State Engineer into the Oregon Water Resources Department (OWRD) in 1975. The ORWD is the state agency that monitors and regulates Oregon water resources. A separate organization, the Oregon Water Resources Commission (OWRC), was created in 1985 to oversee the activities of the OWRD and to establish policy and programs for the management of water resources in the state. The OWRD and its director administer policies and programs established by the OWRC (OOSSAD 2007).

The OWRC is comprised of seven, governor appointed members from different regions of the state serving four-year terms (OOSSAD 2007). The eighth member is the OWRD Director.

The OWRD has five primary tasks: (1) allocating and overseeing surface and groundwater rights; (2) collecting data about water resources; (3) overseeing the construction of wells and hydraulic structures; (4) dam safety; and, (5) water resource planning. Unfortunately, the ORWD has not been well funded over the last two decades. One result of the lower funding levels is a reduction in the number of employees from 161 in 1999 to 139 in 2007 (Zaitz 2009). The ORWD is challenged to meet increasing demands, in particular, for overseeing water rights which have tripled in number from 24,000 in 1955 to 85,000 today, data collection, and planning with fewer employees and a reduced budget (Neuman *et al.* 2006; Zaitz 2009).

The OWRD has five divisions: (1) Water Rights and Adjudications; (2) Field Services; (3) Technical Services; (4) Administrative Services; and, (5) the Director's Office. The Technical Services Division within the OWRD performs groundwater and surface water hydrology studies. The OWRD has obtained information about surface water resources for most of the state except for parts of south central Oregon comprising about 20-25 percent of the state land area as shown in Figure 2.3 (Norris 2006).

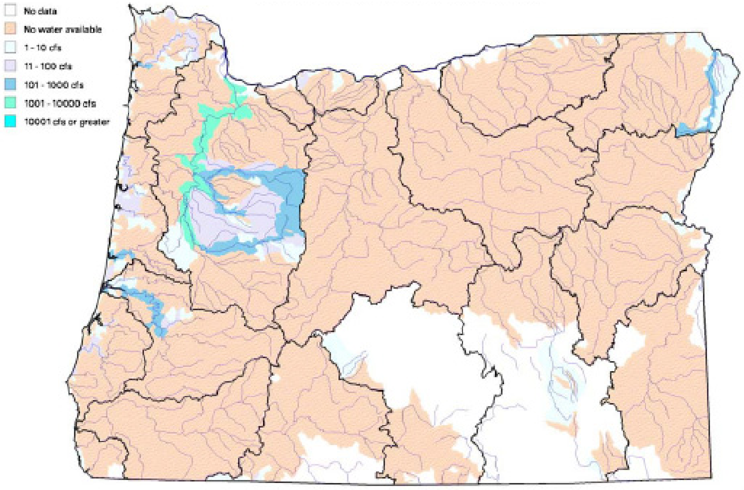

Figure 2.3 Surface water data for Oregon where beige indicates no water available for appropriation in late summer (Norris 2006).

The OWRD has much less information about Oregon groundwater resources than surface water resources. To date OWRD has groundwater information for roughly 25 percent of the state or just three of 18 basins (Zaite 2009). The lack of data and information makes it difficult to manage the water resources in these unquantified areas since there is insufficient information about water availability to use to compare against existing and proposed water rights. The need for data is critical given the increasing demands for an already limited water resource. Unfortunately, at current staffing and funding levels, it will take time for the OWRD to complete the remaining groundwater studies (Boggess and Woods 2000).

Recently, the OWRD conducted a Water Availability Analysis on surface water statewide. This analysis showed that during the high flow use season (i.e., summer irrigation season), there is next to no water available for new appropriations. This finding is somewhat surprising given the common misperception that the PNW is a water rich region. However, the path to over-appropriation began decades ago as more permits were issued than water was available to fill them (Neuman *et al.* 2006). The physical amount of water available is one limitation. Policies also constrain the amount of resources available such as managing surface and groundwater conjunctively; instream water rights; the 80 percent exceedance level rule; and, peak flow protection. These policies are discussed in more detail in the next section.

Legal Framework

Oregon is a prior appropriation state and under Oregon Water Law all surface and groundwater belongs to the public with a few minor exceptions providing for exempt uses (telephone interview, June 16, 2009).[10] The Oregon legislature passed a comprehensive Water Code in 1909 that established the doctrine of prior appropriation for Oregon water rights and required permits for new water rights (Neuman *et al.* 2006). Originally, the Water Code required the State Engineer's Office, now the OWRD, to

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[10] Surface water exempt uses include: landowner's use of natural springs; stockwatering; water for salmon bypass structures and related uses; fire control; forest management; and rainwater collection and use (OWRD 2001). Groundwater exempt uses include: stockwatering, lawn watering of less than 0.5 acre; domestic wells not exceeding 15,000 gallons; and commercial uses not exceeding 5,000 gallons per day; and, other similar uses (OWRD 2001).

approve permits for beneficial use[11] of water unless the proposed use conflicted with other water rights (Neuman *et al.* 2006). Like Washington, Oregon manages groundwater and surface water conjunctively and considers both surface water and groundwater when allocating new water rights (telephone interview, June 16, 2009). Whenever a groundwater right application is requested, the OWRD investigates whether or not that right would affect existing groundwater withdrawals as well as existing surface water rights (telephone interview, June 16, 2009; ORWD 2001). If the proposed new use of groundwater will affect surface water and there is no additional water available for surface water allocation, then OWRD will not issue the groundwater right. Given so many surface watersheds are already fully allocated, new groundwater permits are often difficult to obtain. One of the challenges posed by conjunctive management of surface and groundwater is that proper management is information intensive. Because some 25 percent of surface water and 75 percent of groundwater basins are yet to be fully analyzed, the lack of information has contributed to over-allocation of some basins in spite of the impetus to employ conjunctive management. As a result, the ORWD has had to restrict pumping in several basins including in the Umatilla Basin because too many water permits were issued and there was not enough water to supply the demand (Zaite 2009).

Policies regarding instream flows, the exceedance streamflow approach, peak flow protection, and scenic river designations further complicate water availability in Oregon. A 1955 overhaul of the Oregon Water Code required the State Water Resources Board establish minimum flows to protect aquatic habitat, recreation, and dilute pollution (Neuman *et al.* 2006). The 1987 Instream Water Rights Act converted all existing minimum streamflows into instream water rights with priority dates between 1955 and 1987 (Neuman *et al.* 2006). Today, there are 1,400 to 1,500 instream water rights across the state (telephone interview, June 16, 2009). However, on average only 60 percent of instream rights are fulfilled in late winter and early spring and only 20 percent of instream water rights receive their full allocation in late summer (Boggess and Woods

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[11] State recognized beneficial uses include: aquatic life, commercial, domestic, fire protection, fish, groundwater recharge, industrial, instream flow, irrigation, mining, municipal, pollution abatement, power, recreation uses, and wildlife (OWRD 2001).

2000). A second policy that impacts water resource allocations in the state is the exceedance stream flow approach. The WRD analyzes the amount of water in a stream and calculates the amount of water available for allocation as the stream flow value that is met or exceeded 80 percent of the time (i.e., streamflows met or exceed levels eight out of ten years). This approach is designed to result in a more conservative assessment of water availability than might otherwise be assumed. A third policy stems from a 1970 Scenic Waterways Act that prohibits new diversions on designated stream segments upstream of a scenic waterway unless "that diversion is consistent with the free-flowing character of the streams and protective of recreation, fish, and wildlife" (Neuman *et al.* 2006). This Act, together with the federal government's Wild and Scenic Rivers Act of 1968, protects over 1,200 miles of Oregon's scenic waterways from further major water development or diversions (Boggess and Woods 2000). The many competing demands for instream and out of stream uses make for a challenging water management task particularly given much of the surface water and a large amount of the groundwater in the state is allocated or over-allocated during the low flow periods of late summer and early fall (Boggess and Woods 2000; telephone interview, June 16, 2009).

Planning

Oregon is one of only two Western states without a state water resource plan to address current and future water needs (telephone interview, June 16, 2009; Snell and Colbert 2007). The Governor and legislature recently worked together to address this deficiency by funding the Oregon Water Supply and Conservation Initiative (WSCI) in 2007. The WSCI includes: an assessment of existing and long-term water supply needs; an inventory of potential storage sites; analysis of conservation opportunities; and, community planning grants among other things. Water resources information obtained through the WSCI will feed into a strategic water resources study that will eventually comprise part of the State Water Plan that will determine how to put the pieces together and plan for future uses. At the local level, the state requires Water Management and Conservation Plans (WMCPs) for municipal water suppliers under water right permit conditions (telephone interview, June 30, 2009). The Field Services Division within

OWRD works with municipal water suppliers and irrigation districts to assist in the development of water management and conservation plans (OOSSAD 2007).

2.3.1.3 Idaho

State Agency

The Idaho Legislature established the Office of the State Engineer, the precursor agency to the Idaho Department of Reclamation, in 1895.[12] In 1919, the Office of the State Engineer became the Idaho Department of Reclamation, signaling the focus on developing water resources for irrigation.[13] In 1970, the name is again changed to the Idaho Department of Water Administration. The Idaho Water Resources Board (IWRB), created in 1964 by a constitutional amendment,[14] is primarily concerned with state level water resource policy and planning (telephone interview, June 8, 2009). Ultimately, the Department of Water Administration and the IWRB were combined to form the Idaho Department of Water Resources (IDWR). The IDWR is the State Regulatory Agency that administers and manages water (telephone interview, June 8, 2009). The IDWR has several authorities including: (1) the allocation of surface and groundwater rights within the state (Hecox 2001); (2) helping adjudicate water rights; (3) inventorying, monitoring, assessing, and managing the state's surface and groundwater; (4) coordinating weather modification efforts designed to increase water supplies;[15] and, (5) dam safety. The IDWR undertakes surface water simulation, groundwater modeling, and geographic information and mapping to support the administration and management of water resources.

By statute, the governor appointed director of IDWR must be a registered Professional Engineer in Idaho. This registration requirement helps insulate the IDWR from purely

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[12] "Key dates in the 169-year history of Idaho water development" published Jan. 16, 2006, *Idaho Statesman.* Retrieved from http://www.lakescommission.com/Home/KeyDatesinthe169YrHistoryofIDWaterDev.pdf

[13] Retrieved from http://www.idwr.idaho.gov/AboutIDWR/history/history.htm

[14] Ibid.

[15] In 1994 the Idaho legislature added weather modification coordination to the duties of the IDWR (IDWR 2001).

political appointments and reflects the fact that the IDWR used to be the Office of the State Engineer (telephone interview, June 16, 2009). The IDWR through their Water Planning Bureau provides staff and support for the Idaho Water Resource Board (IWRB) (telephone interview, June 8, 2009; telephone interview, June 16, 2009). The IWRB is a governor appointed Board of eight members who serve 4-year terms and who are responsible for the policy and planning aspects of water resources for the state (telephone interview, June 16, 2009). The IWRB has essentially equivalent standing to the Director of the IDWR since both are appointed by the governor. The IWRB provides administrative and policy guidance to the IDWR and other state agencies, develops water policy for the state, develops and implements the State Water Plan, manages the state water bank, and administers grants for water infrastructure development (telephone interview, June 8, 2009; Hecox 2001). The Board sets and adopts policies, which in turn must be reviewed and approved by the Legislature but these policies remain in effect even if the Legislature does not approve them (telephone interview, June 16, 2009). For example, the Board may adopt a plan for a certain river basin which then goes to the Legislature for approval. The Legislature can choose not to approve it but the plan remains in place. The Water Resources Board also has the authority to designate state protection – natural or recreational protection – for water bodies (telephone interview, June 8, 2009). The Board appropriates and holds instream flow rights in trust for the state (telephone interview, June 8, 2009; Hecox 2001).

Planning

The Idaho Water Resource Board (IWRB) has several planning authorities including the State Water Plan and Comprehensive Basin Plans. Article XV, Section 7 of the Idaho Constitution provides the IWRB with the authority for the preparation of the State Water Plan (IWRB 2007). The State Water Plan, Part A is the overarching policy for the state and for major river systems like the Snake, Salmon, and Bear. The next level of planning authority is the Comprehensive Basin Plans, State Water Plan Part B. The IWRB is currently focusing on the Comprehensive Aquifer Management Planning effort for surface and groundwater resources across 10 basins.

Legal Framework

Idaho manages and administers both surface water and groundwater through the Prior Appropriation Doctrine (telephone interview, June 8, 2009). The Idaho constitution and laws designate waters of the state as belonging to the public. Water rights enable rights holders to divert public waters for beneficial use (Hecox 2001).[16] New surface and groundwater rights are established through permits although some uses are exempt from the permit process.[17] The Idaho Constitution (Article XV, Section 3) establishes the priority of uses with domestic listed as the highest use, then mining and milling, agriculture, and manufacturing (IDWR 2001).

Idaho water statutes recognize conjunctive management in cases where there is a hydrologic connection between surface and groundwater resource. In these cases, the statute requires that the surface and groundwater be managed conjunctively as a single resource. While conjunctive management has been in the statute for a long time, in practice surface and groundwater resources have been managed separately (telephone interview, June 8, 2009). The State is now working to implement the laws consistent with the statute. Managing the resource conjunctively is important given the conflicts that have arisen in parts of the state including the Eastern Snake Plain in Southern Idaho (telephone interview, June 16, 2009). Managing the resource conjunctively protects more senior surface water rights holders from more junior groundwater rights holders withdrawing water from the hydraulically connected aquifer system (Dreher 2005). A 2009 revision of the State Water Plan calls for conjunctive management in the approval of new water-use applications as well as the administration of existing water rights:

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[16] State recognized beneficial uses include: aesthetics, aquatic life, commercial, cooling, domestic, fire protection, fish propagation, ground water recharge, industrial, instream flows, irrigation, manufacturing, mining, municipal, navigation and transportation, power, recreational use, stock watering, water quality control, and wildlife (Hecox 2001).

[17] Exemptions from the water rights permitting process include: small domestic groundwater withdrawals and surface water used to water livestock (Hecox 2001; IDWR 2007). Groundwater withdrawals that are exempted for "domestic purpose" is limited mainly to single-family domestic purposes, but is defined by statute as "water for homes, organization camps, public campgrounds, livestock and for any other purpose in connection therewith, including irrigation of up to one-half acre of land, if the total use is not in excess of 13,000 gallons per day, or any other uses if the total use does not exceed a diversion rate of 0.04 cubic feet per second and a diversion volume of 2,500 gallons per day." (Hecox 2001; IDWR 2007)

> *"The goal of conjunctive administration is to protect the holders of senior water rights while allowing for the optimum development and use of the state's water resources. Nearly all ground water aquifers in the state discharge to or are recharged by bodies of surface water. Aquifers, in turn, serve as underground reservoirs, and can stabilize stream and spring discharge during dry periods. The approval of new water-use applications and the administration of existing water rights must recognize this relationship."- IWRB 2009*

It is uncertain if the language recommending consideration of the surface and groundwater connection in the issuance new water permits will remain in the final State Water Plan since this draft plan is not yet finalized. The plan must undergo a public review and comment period and then is put before the legislature for adoption.

Other water policies of interest include those protecting instream flows and other instream uses. For example, the Idaho Legislature recognized the need to protect instream flows for scenic beauty, health, and recreation purposes as early as 1925 (IWRB 1996). In 1976, the IWRB completed its first State Water Plan which called for a statewide instream flow program. The State now holds 76 minimum stream flow water rights totaling 445 stream miles and 4 million acre feet of water in area lakes (IWRB 1996). Additional protection was provided by legislation in 1988, which gave more authority to the IWRB to preserve highly valued waterways extending protections to 1,700 miles of rivers (IWRB 1996). The 1968 Wild and Scenic Rivers Act protected another 577 river miles (IWRB 1996).

Idaho has also developed policies to respond to groundwater related issues. For example, some groundwater basins have become stressed by continued use and have exhibited declines over time. The IDWR established Groundwater Management Areas (GWMA) where groundwater level declines are a concern to ensure existing water rights are not adversely affected by the issuance of new water rights. A second designation is for Critical Groundwater Areas (CGWA). This designation means that the groundwater level decline is severe enough that it threatens existing users. In CGWA, there is not sufficient groundwater available to supply irrigation or other uses at the current or projected rates of withdrawal (Harrington and Bendixsen 1999). In this case, the Director of IDWR can deny a proposed new groundwater permit. Figure 2.4 shows the nine GWMAs and eight CGWAs currently designated in the state (IWRB 1996).

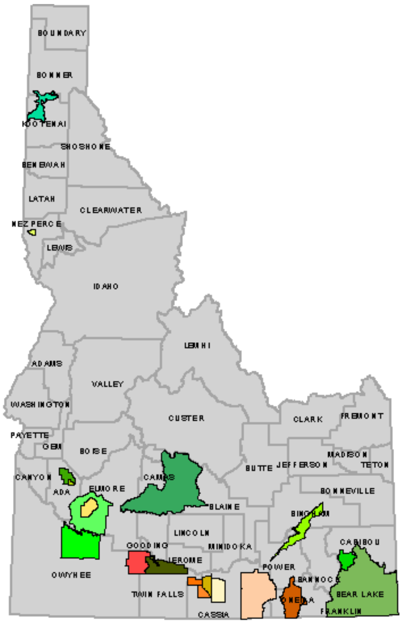

Figure 2.4 Idaho designated groundwater management areas (IWRB 1996).

The GWMAs and CGWAs are primarily in the southern part of the state where most of the population resides and where groundwater withdrawals make up for lower precipitation rates and surface water availability. The legislature approved the establishment of groundwater districts in 1995 to help manage groundwater basins.

2.3.2 Southwest States

As in the Pacific Northwest, the state governors of the Southwestern states also have a limited role in water resources policy and management. The state governor generally has a limited role in water resources policy and management at the local level though may play a larger role at the state or executive level. The governor may declare droughts and emergencies, form advisory bodies, enact new policies through executive order, etc. While the governor may influence statewide activities, the policymaking authority for state agencies and departments lies with the legislature and with the rule making functions of the state agencies whose authority is established by legislative action. The legislature and state agencies may also exert influence over local level water managers through new laws and rules.

2.3.2.1 Arizona

State Agency

The Arizona Interstate Stream Commission (AISC) was the first agency established by the Arizona Legislature to manage water for Arizona. The AISC was tasked with securing Arizona's water rights to the Colorado River and statewide water planning. The administration of water rights rested with the Land Department (ADWR 2009). The AISC existed for 23 years until it was replaced in 1971 by the Arizona Water Commission which itself was replaced nine years later by the creation of the Arizona Department of Water Resources (ADWR) with the passage of the 1980 Groundwater Management Act (ADWR 2009; Jacobs and Holway 2004). The ADWR was charged with: (a) administering and enforcing water rights for groundwater and surface water; (b) protecting Arizona's rights to the Colorado River and representing the state in negotiations of water rights with the federal government; (c) administering state water laws except those regulating water quality; (d) collecting and analyzing water resources data and comprehensively managing the use of water resources; (e) developing policies to promote conservation; (f) participating in flood control management and planning; (g) conducting statewide water resources planning for surface and groundwater resources and developing groundwater management plans for designated Active Management Areas (AMAs); and, (h) inspecting dams (ADWR 2009). The ADWR is organized into six divisions: (1) Water Management, which houses the staff focused on AMAs; (2) Hydrology, the technical arm of the ADWR that does modeling, hydrology, and monitoring statewide; (3) Statewide Management, which deals with water supply and related issues outside of the AMAs; (4) Surface Water, which deals with Colorado River issues, dams, and state compacts; (5) Technology, which supports computers, programs, and software; and (6) the Legal Division, which houses ADWR attorneys that deal with water issues (telephone interview, April 13, 2009). The Director of the ADWR is appointed by the Governor and confirmed by the Arizona Senate (ADWR 2009).

AMAs are areas within which heavy reliance on groundwater created severe overdrafts of the underground aquifers (ADWR 2010). Originally, four AMAs were created - Phoenix, Pinal, Prescott, and Tucson. A fifth AMA, the Santa Cruz AMA, was formed from a portion of the Tucson AMA in 1994 (ADWR 2010). The AMAs are home to over 80 percent of the population of Arizona. These areas represent half the total water used in the state and 70 percent of the state's groundwater overdraft yet the land area is comparatively small representing only 23 percent of the total land area of Arizona (ADWR 2008; Jacobs and Holway 2004). AMA boundaries approximate aquifer boundaries. The five AMAs are illustrated in Figure 2.5. AMAs have advisory boards called Water User's Advisory Councils that serve as a sounding board and advisor to the AMA. Membership for Councils are drawn from the AMA and appointed by the Governor. The Governor or state legislature provides directives for AMAs through the ADWR. An AMA may initiate policy making through the administrative rule making process. However, any change in rules or new rules must go through a public comment period and be reviewed and approved by the Governor's Rules Review Committee.

Figure 2.5 Arizona Active Management Areas.

Legal Framework

In Arizona, surface water is subject to the doctrine of prior appropriation as defined by the 1919 Public Water Code (Pearce 2006). Post-1919 water rights require a permit and certificate from the ADWR for the beneficial use of surface water.[18] By definition, surface water includes not only flow above the ground but also "subflow," which is considered part of the stream rather than a separate groundwater source. This definition appears to recognize the hydraulic connection between surface and groundwater. However, management of water resources in Arizona belies this connection except in the case of groundwater pumping near the Colorado River. In practice, a conservative identification of the "subflow zone" in the Arizona state courts effectively disconnects surface water from groundwater and does not protect surface water rights holders from groundwater pumpers' reasonable use. This restrictive definition was put forth by the Supreme Court of Arizona in the case of the Gila River Adjudication where the Court defined the "subflow zone" as being immediately below and adjacent to a stream and excluded the adjacent tributary or basin-fill aquifers even though those aquifers may be hydraulically connected to the stream (DuMars & Minier 2004).

The Arizona Legislature amended the Public Water Code in 1941 to include wildlife and fish as beneficial uses of appropriated water (Hecox 2001). A later 1976 court case found the additional beneficial uses constituted instream uses. Beyond this designation for beneficial use, Arizona does not have any specific laws to protect species (Gelt 1996) and generally, the state does not provide for ecosystem benefits. However, Endangered Species Act provisions do provide for protections in some areas of the state. For example, there is a Multi-Species Conservation Plan for the Lower Colorado River to mitigate the effects of reservoir operations on threatened and endangered species (Graham 2006). The Verde and San Pedro Rivers are two other areas where water management challenges center on the need to protect habitat while simultaneously sustaining population and economic growth.

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[18] Beneficial uses include domestic, municipal, irrigation, stockwatering, power, mining, recreation, wildlife and fish, and groundwater recharge (Hecox 2001).

Unlike in the Pacific Northwest, groundwater is regulated and administered separately from surface water by the ADWR. Arizona groundwater law developed over time through the legislature and the courts in response to conflicts among “individual users over their immediate and specific needs” (Hansen and Marsh 1982). The first groundwater issue to develop, which persists to this day, was the rapid lowering of aquifer levels in the early 1930s and 1940s due to the development and use of groundwater resources for mining, agriculture, and public water supplies across the state (Hansen and Marsh 1982). The Arizona Legislature passed the first groundwater law in 1945 mostly to provide information on wells and acquire data. In 1948, amidst a prolonged drought, the legislature attempted to limit extraction in some areas by passing the first Groundwater Code. The 1948 Groundwater Code designated critical groundwater basins and restricted new agricultural development in those areas (Hansen and Marsh 1982). Still, this legislation did little to abate the rampant mining of groundwater or to protect more established groundwater pumpers from newer groundwater users. In fact, there continues to be no protection for priority rights of groundwater users because groundwater is excluded from the doctrine of prior appropriation. Instead, Arizona applied the “American rule” of groundwater use permitting land-owners to access groundwater for “reasonable use” (ADWR 2009; DuMars & Minier 2004; Pearce 2006).

Groundwater mining continued unabated until the Groundwater Management Act (GMA) was signed into law in 1980 ostensibly a result of Federal haranguing – conditioning the authorization of CAP to groundwater management reforms (Jacobs and Holway 2004). The GMA restricted groundwater pumping to achieve or maintain safe yield by 2025 within designated Active Management Areas (AMAs) and restricted any increase in irrigated acres in designated Irrigation Non-Expansion Areas (INAs) (ADWR 2009). The regulation of AMAs has a fairly broad impact given most of the population resides within AMA boundaries and half of the total water used in the state occurs within AMAs (Jacobs and Holway 2004). INAs include Douglas, Joseph City, and Harquahala (ADWR 2009; Hecox 2001). Figure 2.6 illustrates the location of INAs.

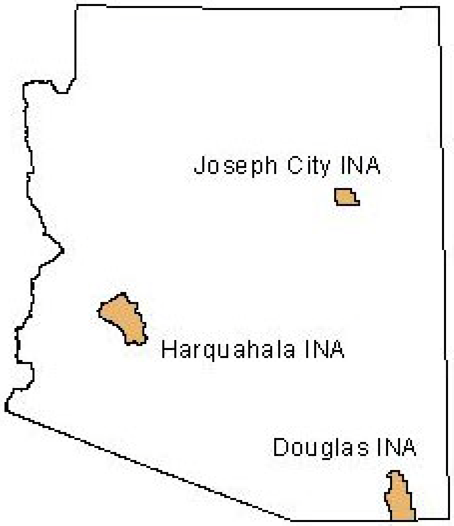

Figure 2.6 Arizona INAs.

The GMA requires new appropriators within AMAs to obtain a permit from the ADWR for withdrawals and submit annual groundwater use reports (ADWR 2009). The GMA also requires adherence to mandatory conservation rules within AMAs (telephone interview, March 12, 2009). Groundwater rights holders that pre-date the GMA are grandfathered by the system (Colby *et al.* 2006). Users within INAs must submit annual groundwater reports and register the well. The regulations restrict new agricultural withdrawals within AMAs and limit new agricultural withdrawals in INAs. However, there are no restrictions on non-irrigation withdrawals in INAs (Jacobs and Holway 2004). And, outside of AMAs and INAs, groundwater is not regulated and does not require a permit (ADWR 2009; Hecox 2001). Also, any well that is exempt – wells with a pumping capacity less than 35 gallons per minute used for household and domestic use – are not regulated anywhere in the state (Pearce 2006). The GMA provides a regulatory structure for AMAs; however, outside of AMAs Arizona's regulatory framework is much weaker (Holway 2006).

The GMA also required all new residential subdivisions within AMAs have a 100-year "assured water supply" (Pearce 2006). The Assured Water Supply Rules were adopted in 1995 supplementing an earlier 1973 consumer protection law that requires demonstration of availability of a 100-year water supply in areas of the state not designated as AMAs

(Holway 2006). However, to ease these restrictions in development as a result of the 100-year water supply requirement, the State created the Central Arizona Groundwater Replenishment District (CAGRD) in 1994. The CAGRD allows new developments to use existing groundwater that will be replenished by the CAGRD using CAP or other renewable water sources (Pearce 2006). Unfortunately, the CAGRD has already promised much more replenishment than it is currently able to provide – a situation which may be problematic in future years when build-out increases water demand (Holway 2006; R. Glennon, personal interview, December 9, 2008). In addition, the CAGRD is not required to replace groundwater in the location where it was withdrawn. While this makes practical and economic sense, it means groundwater mining may continue in parts of the aquifer due to excessive withdrawals while other parts of the aquifer benefit from recharge.

Outside AMAs, Arizona's regulatory structure is weaker. One example is the 1973 consumer protection law requiring developers of subdivisions outside of AMAs to obtain a determination from the ADWR of whether there is sufficient water of adequate quality available for 100 years. The adequacy determination sounds restrictive and protective of consumers but, in fact, the law is quite limited. Lots may still be developed and sold even if the water supply is determined to be inadequate on the condition that the lack of water is disclosed to the first buyer never mind any subsequent owners. Legislation adopted in June 2007 (SB 1575) goes a step further authorizing a county board of supervisors to adopt a provision by unanimous vote that requires a new subdivision have an adequate water supply to be approved by the county platting authority. If adopted, cities and towns within the county may not approve a subdivision unless it has an adequate water supply. If the county does not adopt the provision, the legislation allows a city or town to adopt a local adequacy ordinance that requires a demonstration of adequacy before the final plat can be approved. To date few counties, cities or towns have adopted the provisions of SB 1575.

The 1922 Colorado Compact apportions Colorado River water between the upper basin states (Wyoming Colorado, Utah, and New Mexico) and the lower basin states (Arizona, California, and Nevada). The 1928 Boulder Canyon Project Act (45 Stat. 1057) approved the Compact signed by all the states except Arizona, authorized construction of the Hoover Dam which created Lake Mead, and apportioned Colorado River water among the lower basin states providing California with 4.4 million acre-feet (MAF), Arizona with 2.8 MAF and Nevada with 0.3 MAF (Pearce 2006). Arizona finally ratified the Compact in 1944 and petitioned the Congress to approve the Central Arizona Project (CAP) to deliver 1.5 MAF (up to 1.8 MAF capacity) of Colorado River water to central Arizona. The Colorado River Basin Project Act of 1968 (Public Law 90-537) authorized the construction of CAP, and required the creation of the Central Arizona Water Conservation District to administer CAP water. The 1968 Act also subordinated CAP water to California such that in times of shortage, CAP water has the lowest priority among lower basin state water uses (Pearce 2006). Due to concerns that other states would perceive Arizona's lack of use of CAP water as a reason to reduce the state's allocation, in 1996 the state of Arizona created the Arizona Water Banking Authority to maximize the use of the state's 2.8 million acre-feet share of Colorado River water. The water is delivered to central and southern Arizona via the CAP and delivered to water users. Any water remaining is injected into underground aquifers to be pumped out and used in the future (DuMars & Minier 2004; Pearce 2006). The Bank enables Arizona to store water for anticipated future water shortages on the Colorado River (telephone interview, March 12, 2009). An agreement with Nevada expanded the role of the bank to include storing water in Arizona for future use (Colby *et al.* 2006).

An ongoing, extended drought in the Colorado River Basin precipitated declining reservoir levels and with it the potential for conflict over water resources that provide over 27 million people with drinking water and irrigation water for over 3.5 million acres of farmland. These conditions spurred action to establish procedures to allocate water under shortage conditions to avoid conflicts. On December 13, 2007 the Secretary of the Interior, Dirk Kempthorne, approved the Record of Decision (ROD) for the Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead which provides a roadmap for allocation of Colorado River water in shortage conditions (USBR 2007). In addition to providing rules for allocation, the ROD also encourages conservation, planning for shortages, coordinated operation of Lake Powell and Lake Mead, and flexibility to deal with climate change and deepening drought (USBR 2007).

Arizona regulates the quality of treated wastewater but does not regulate the use or sale of treated wastewater effluent. Even though the wastewater arriving at the plant might have originated as surface water or groundwater, once treated, the effluent is an entirely different class of water. This lack of regulation means municipal governments, county governments, and private utilities may sell effluent and transfer the effluent to a point of use. The state is increasingly using effluent as an important water source.

Planning Authorities

The need to provide water in times of drought and to meet demands for growth have prompted increased attention to water planning in the state and to the need for data and monitoring to support planning. Early planning efforts were not statewide; instead, they focused on AMAs, a requirement of the 1980 Groundwater Management Act. Once AMA planning was underway, the ADWR began to shift more attention to statewide planning over time. However, a lack of funding delayed statewide planning in the 1990s. The first statewide water assessment undertaken to support a statewide planning effort was not completed until 1994. The 1994 Statewide Water Resources Assessment provided a broad overview of water supply and demand and identified water management issues across the state (Jacobs and Stitzer 2006). Even with this important step completed, statewide planning did not advance significantly until 2002 when ADWR began focusing more on communities outside AMAs (telephone interview, March 12, 2009). Recently, ADWR developed a Water Atlas containing information for 51 groundwater basins, surface water hydrology, and effluent use in seven planning areas (ADWR 2010b).

The impacts of the recent drought from 1998-2004 focused attention on developing a state drought plan to limit the most severe impacts and the development of a Statewide Water Conservation Strategy for longer term water use reduction (Jacobs and Stitzer

2006). Local level planning for community water systems (CWSs) is just getting underway. The Legislature passed the Community Water System Planning and Reporting Act in 2005 to spur local CWSs to plan to ensure they reduce their vulnerability to drought and prepare to respond to potential water shortage conditions.

2.3.2.2 New Mexico

State Agency

The New Mexico Office of State Engineer is the State agency that administers water resources including the "supervision, measurement, appropriation, and distribution" of groundwater and surface water in the state (NMOSE 2005). The State Engineer's role in administering water resources began as early as the mid-1850s when New Mexico was a territory.[19] The NMOSE has three branches – Program Support, Water Resource Allocation Program (WRAP), and Litigation and Adjudication – and also houses the Interstate Stream Commission Program (ISCP).[20] The WRAP is responsible for: (1) processing water rights applications and conducting research to support those water rights decisions; (2) maintaining water rights records; (3) inventorying and monitoring water resources and water use and enforcing any conditions or restrictions on water use; (4) cooperating with the U.S. Geologic Survey in monitoring groundwater levels throughout the state; (5) licensing all well drillers; (6) inspecting non-federal dams; (7) evaluating subdivision water-supply plans submitted by counties; and, (8) promoting water conservation.[21] WRAP water masters "measure stream flow, allocate the water within a stream system based on state water law, and regulate and control diversions."[22]

The State Engineer serves as Secretary of the Interstate Stream Commission (ISC), which oversees the ISCP, a very small, sister agency to the Office of the State Engineer (telephone interview, April 6, 2009). The nine-member ISC, which oversees the ISCP, consists of eight governor appointed members who serve four or six year terms and the ISC Secretary, a role filled by the State Engineer. Historically, the eight appointed

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[19] Retrieved from http://www.crwua.org/coloradoriver/memberstates/index.cfm?action=newmexico
[20] Retrieved from http://www.ose.state.nm.us/PDF/ProgramSupport/org_chart.pdf
[21] Retrieved from http://www.ose.state.nm.us/water_info_index.html
[22] Ibid.

commissioners represented agricultural interests. Today, they represent agricultural interests, municipal interests, Pueblo Indian interests, environmental interests and are from different regions of the State. The appointed commission plays a limited but important role by providing guidance and feedback to the ISCP; but, generally, the ISCP operates fairly independently of the appointed commission.

The primary function of the ISCP is to: (1) protect New Mexico's rights to water in eight interstate river basins; (2) ensure New Mexico complies with interstate compacts in each interstate basin; (3) conserve, develop, and investigate the waters of the State (telephone interview, April 6, 2009); and, (4) oversee state and regional water planning. The ISCP has technical staff that supports these primary functions including modeling reservoir flows, reservoir routing, and rivers. Modeling helps inform the development of an annual operating plan for the rivers, long-term planning, regional water planning, and NEPA exercises with Federal agencies. Ensuring compliance with interstate compacts begets a number of important secondary functions and involves a wide range of activities including river and channel maintenance, building new infrastructure, purchasing water rights, and communicating with key state agency counterparts in Colorado and Texas, with the Federal agencies including the Corps of Engineers, Bureau of Reclamation, and U. S. Fish and Wildlife Service, in particular, and with individual water users in New Mexico (telephone interview, April 6, 2009).

Legal Framework

Surface waters were developed prior to groundwater and, as a result, were regulated first (Brockman 2009). The 1907 New Mexico Water Code (Water Code), created to govern surface water, emphasized the basic principles of the prior appropriation doctrine recognizing public ownership, beneficial use as the measure and limit of a water right, and the priority of time as the method of apportioning supplies among existing water rights (Hall 2008). The Water Code established the Office of the State Engineer (OSE) and granted the OSE expansive authority to make "fundamental water decisions" for the state (Hall 2008). Individuals may obtain rights to use public waters but they do not own the water and the right to use the water can be lost by non-use (White 1984). The state legislature extended the 1907 Water Code to groundwater in the early 1900s and in so doing applied the prior appropriation doctrine to groundwater (Hall 2008; White 1984). The state legislature enacted the New Mexico Groundwater Code in 1931, which established a permit system for new appropriations in "declared" underground basins (Brockman 2009; White 1984).[23] By limiting the Groundwater Code to "declared" basins, the New Mexico Legislature effectively limited the administrative control of groundwater between 1931 and 2005 to only those areas of the state where groundwater was being used in significant quantities that threatened existing "intrastate or interstate rights" and that had "reasonably ascertainable boundaries" (Brockman 2009). Individuals could still obtain a groundwater right through common law in undeclared basins. In 2005, the State Engineer declared the remaining basins effectively extending the Groundwater Code to the 108 separate groundwater basins in the state (Brockman 2009). A new appropriator may obtain a new groundwater right if: (1) there is unappropriated water available, (2) the new appropriation does not impair existing water rights, (3) the new right will not be detrimental to public welfare, and (4) the new right is not contrary to conservation (Brockman 2009). New Mexico surface waters are generally fully appropriated.

In 1956, the State Engineer adopted and in 1962 the New Mexico Supreme Court approved conjunctive management principles for interconnected surface and groundwater in *Albuquerque v. Reynolds* (Brockman 2009; White 1984). Conjunctive management was driven by increasing demands of both surface and groundwater resources that were impeding the state's ability to meet compact delivery obligations in the Rio Grande and in other areas of the state (i.e., Pecos River Basin) (Brockman 2009). Now, impairment determinations for new appropriative groundwater rights must take into account the potential for impacts on existing hydrologically connected surface water rights and other groundwater rights. Conjunctive management has been applied throughout the Middle Rio Grande requiring offsetting groundwater withdrawals that impact surface water.

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[23] The State Engineer does not regulate domestic wells. Originally the limit for unregulated domestic well withdrawals was 3 acre feet per year. The amount was recently revised to one acre feet per year. Approximately 18 percent of NM residents rely on domestic wells which withdraw approximately 9 percent of the water used for domestic and related needs (NMOSE 2000). Perennial streams suffer depletions of 5,800 to 16,312 acre feet per year from existing domestic wells and 1.2 million acre feet over the 30-year lifetime of the almost 137,000 existing wells (NMOSE 2000).

Planning

New Mexico engages in planning at both the state and regional levels. State and regional planning was initiated when the New Mexico Legislature created separate programs under the auspices of the ISC in 2005 (NMOSE 2005). The first State Water Plan was developed five years before all the regional water plans were completed and contains mainly general policies and approaches. Regional water plans are more detailed including population and economic growth projections and related water supply and demand projections. New Mexico also engages in state level drought planning organized through the Governor's Office. There are no specific planning requirements for community water systems (CWSs). CWSs are "encouraged to have drought conservation plans and to do emergency planning but it is not a requirement" (R.P., June 17, 2009). CWSs are also encouraged to enact water conservation policies and to undertake source water and wellhead protection programs to limit potential sources of water contamination (NMED 2008).

Chapter 3

Literature Review

Scientific information is important for providing a basis for decision making; however, science is rarely the only criterion upon which decisions are made (Power *et al.* 2005). One of the primary goals of federally funded scientific research including federally funded integrated assessments is to help bring scientific information to bear to solve societal problems. To help solve problems the information must be useful and used to inform decision making – two related goals that are surprisingly difficult to achieve in practice. This dissertation aims to help improve our understanding of the multiple challenges faced when attempting to provide useful information to improve societal well-being.

To place this dissertation in context, first a review of the literature is conducted to describe the relationship between federal science funding and society including how this relationship has changed over time and how that evolution affects the conduct of assessments. Next the role of boundary organizations, organizations that facilitate the link between science and policy, is explored including how boundary organizations aim to contribute to the production of usable information. Existing research pertaining to factors that drive or impede information use is then summarized. Lastly, key research about knowledge-action systems and research investigating efforts to build resilience to climate variability and change in the context of water management is reviewed.

3.1 The Social Contract

The federal government supports basic and applied scientific research under the expectation that society receives a benefit. This relationship, between federal funding and expected societal benefits, is known as the social contract for science. Vannevar

Bush described the rationale for the social contract in a report entitled *Science: The Endless Frontier* (1945). The social contract centered on the idea that scientists should govern themselves and that the free flow of ideas and unfettered advancement of knowledge would naturally lead to societal benefits through a presumed linear model of information flow from basic research to applied research and finally to production or use (Bush 1945). On the one hand, Bush defined basic research as research that contributes to “general knowledge and understanding of nature and its laws” (1945). On the other hand, the primary goal of applied research is producing useful knowledge for some identified individual, group, or societal need (Stokes 1997). Bush believed the goal of basic research, understanding, and that of applied research, use, existed in tension (1945). That tension necessitated that each had to be conducted separately to keep basic research unencumbered from any thoughts of utility that could impede the creativity underpinning advancement in basic research.

The relationship between science and society and between basic and applied research has shifted over time. Scarcity of funding, increased governmental oversight, and researcher accountability are partly responsible for that shift. For example, spending for non-defense research and development, not including the National Institutes of Health, has remained flat for the last thirty years even as the number and complexity of problems requiring study have increased (AAAS 2007). This changing relationship between science and society undergirds a shift in the emphasis from basic to applied research reflective of tightening governmental science budgets as well as the need to justify research expenditures in light of growing environmental and other concerns. For example, producing science directed at solving perceived societal problems is a key justification for using taxpayer monies to fund scientific research. This new scientific enterprise might be unrecognizable to Bush were it not for the underlying tenant that science can benefit society even if, and in fact because, science is not entirely separate from society.

3.1.1 Revisions to the Linear Model

The understanding that science is not produced in a vacuum nor is science completely objective and value free and that the utility of information cannot be assumed a priori has led to a reappraisal of the appropriateness of the linear model. New models characterize the evolved relationship between science, scientists, the public, and policy as more flexible, iterative, and interactive, rejecting the separation between science and society espoused in the linear model. For example, contrasting the traditional scientific enterprise characterized by disciplinary focus on basic research problems, designated Mode 1, Gibbons *et al.* (1994) propose a new mode of knowledge production, Mode 2, which is transdisciplinary, heterogeneous, and more socially accountable and reflexive focusing on producing useful knowledge to solve societal problems. On one side, Mode 2 arises from an expansion in and increased diversity of knowledge producers beyond those housed in university settings and, on the other side, from an increase in the demand for specialized knowledge (Gibbons *et al.* 1994). This expansion in the supply of and demand for knowledge has led to the development of a socially distributed knowledge production system. Nowotny *et al.* (2001) expand upon the Mode 2 idea clarifying the conceptual foundation and concretizing the idea that knowledge is contextualized through the interaction of science and society and that science and society co-mingle and co-evolve. Jasanoff & Wynne (1997) introduce the idea of mutual construction or co-production of science and policy. Like Mode 2 science, co-production recognizes the context within which science is produced and used, arguing that it cannot be disenfranchised from the production process. If scientific knowledge "embeds and is embedded in social practices, identities, norms, conventions, discourses, instruments, and institutions" as Jasanoff (2004) suggests, then the separation between science, policy, and society is artificial. Taken together, scholars now argue that the interface between science and policy should be represented as a "hybrid, or mutually constructed arena, where facts about the natural world are shaped by the social relations between scientists and those whom they advise" (Lovbrand & Oberg 2005). To maintain credibility and legitimacy of science and scientists within this contemporary context Sarewitz (2004) argues that values should be negotiated separately from the science to extend and solidify scientific authority over the science that is produced. In other words, by separating the science that informs and supports the development of policy alternatives from the political process involved in choosing among those alternatives, scientists maintain credibility and authority. However, the cost of that separation and enhanced impartiality may be a much more politicized process of alternatives evaluation (Pielke 2004) or a reduction in influence of science on policy making altogether (Oppenheimer *et al.* 2007). Scholars suggest to bridge these science and policy realms, contribute to a less politicized process of evaluation of policy alternatives, and create more impactful assessments requires a managed boundary between science and policy (Gieryn 1995). A managed boundary helps maintain scientific credibility while ensuring through interaction across the boundary that information produced is relevant to policy makers.

3.2 Boundary Organizations and Co-produced Knowledge

Because information does not cross the science-policy divide automatically, there is a need for boundary management in the conduct of science in service of society. Boundary organizations that straddle the divide between politics and science manage the boundary between politics and science by communicating, mediating, and translating the science for policy (Cash *et al.* 2003; Guston 2000). Boundary work undertaken by boundary organizations determines the limits of science and policy through contestation and negotiation (Cash 2001; Gieryn 1995; Jasanoff 1990). This process of boundary demarcation is important given the "untidy, uneven processes through which the production of science… becomes entangled with social norms and hierarchies" (Jasanoff 2004) and the equally messy process of negotiating values. Boundary organizations help span the gap between information producers and information users (Guston 2001; Jacobs *et al.* 2005) exposed by the failure of the linear model by enhancing and sustaining communication between scientists and information users (Sarewitz & Pielke 2007) and by translating information into more useful and usable forms. Boundary organizations involve the participation of actors from the policy and the science realms and participation from "professionals that serve a mediating role" (Guston 2001). Mediation helps resolve conflicts that arise through the boundary spanning process helping to ensure information is useful and usable. Lastly, boundary organizations help facilitate the co-production of knowledge through collaboration and interaction between information producers and users (Guston 2001; Lemos & Morehouse 2005).

The success of boundary organizations depends on satisfying the actors on both sides of the divide and remaining stable throughout the co-production and boundary demarcation processes. According to Guston (2001) stability comes not from isolating the boundary organization from political authority but by being "accountable and responsive to opposing, external authorities." In other words, stability arises from credibility garnered by approval of the science by scientists and legitimacy derived from approval of policy orientations garnered from policy actors (Miller 2001).

The number and type of boundary organizations have continued to expand to fill the burgeoning need for scientific information to inform policy. The European Environment Agency (EEA) is one example of a boundary organization oriented towards providing useful environmental research for the European Union (Scott 2000). The now defunct Office of Technology Assessment (OTA) is another example (Guston 2001). Prior to dissolution in 1995, OTA had achieved a level of respectability as a neutral provider of skilled analysis of highly technical policy problems for the Congress. Also at the U.S. national level the National Research Council (NRC) "provides science, technology and health policy advice" to improve government decision making and policy making.[1] A recent report provides timely advice to the Congress concerning adapting to climate change focusing on facilitating decentralized planning and adaptation actions supported through information and technical resources provided by the federal government (NRC 2010a). Another recent NRC effort focuses on what the federal government should do to improve and maximize the effectiveness of responses to climate change recommending improved, coordinated federal policies, centralized information and reporting systems, and learning from existing response efforts (2010c). Last year, the NRC provided important science policy advice about the direction of the Climate Change Science Program (CCSP) essentially recommending restructuring the CCSP to provide a new "framework for generating the knowledge to understand and respond to climate change"

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[1] Retrieved from: http://sites.nationalacademies.org/NRC/index.htm

(2009, p. 3). The report made a case for maintaining the strength of the disciplinary focus of the CCSP that contributes to improved understanding and prediction of climate change while building cross-disciplinary, human dimensions research components to more effectively generate the knowledge needed to effectively respond to climate change (NRC 2009, p. 4). At a more regional level, Cash (2001) describes how the U.S. agricultural extension system acts as a boundary organization "creating and maintaining an integrated system of assessment and decision making for addressing depletion of the High Plains Aquifer."

Climate variability and climate change research provides another important and fruitful area for the establishment of boundary organizations. For example, the International Research Institute for Climate Prediction (IRI) engages in climate research and modeling to provide useful information to farmers, fishermen, and others who might derive benefit from climate forecasts (Agrawala *et al.* 2001). Regional Integrated Sciences and Assessments (RISAs) are another example of boundary organization focused on providing climate information for a variety of potential information users across diverse sectors (e.g., water, public health, forestry, agriculture). These examples illustrate the diversity of boundary organizations that "facilitate the transfer of relevant and useable knowledge" (Guston 1999) across various science-policy divides.

As the number and type of boundary organizations continued to expand, researchers increasingly sought to study these emergent organizations to improve our understanding of boundary organizations themselves as well as the science-to-policy process. For example, Cash (2001) expanded the one-dimensional view of the science-policy bridge by finding that boundary organizations were not constrained to a single policy dimension but rather worked across scales of decision making. In particular, Cash (2001) showed agricultural extension agents bridged the information needs of local, state, and national decision makers. Miller (2001) has also expanded our understanding of boundary organizations through his analysis of the Subsidiary Body for Scientific and Technological Advice (SBSTA) created by the United Nations Framework Convention on Climate Change in 1992. Miller's (2001) analysis of the SBSTA showed that some boundary organizations, particularly those bridging scientific and policy realms in the international climate regime, are more dynamic and fluid and more intertwined with the political processes they are meant to support. The dynamism and structure of this international boundary organization is described as a hybrid management organization – a subclass of a boundary organization – wherein scientific and political elements are unable to be sufficiently separated to create a more traditional boundary organization. This research suggests boundary organizations can exist in a variety of forms and can interact on a variety of policy levels.

3.2.1 Assessments as Boundary Organizations

Assessments organize, evaluate, and integrate expert knowledge to inform policy or decision making (Jäger & Farrell 2006). The organization, evaluation, and integration of knowledge may also involve the interpretation and reconciliation of information produced from disparate scientific domains to produce information that is more useful for policy deliberations and for addressing an identified problem (Parson 1995). Because assessments generate science to support policy, assessment efforts help bridge the science and policy divide. These organized assessment efforts may function as boundary organizations if they are ongoing, iterative, and produce information aimed at meeting needs of policy and decision makers.

Assessments are conducted at various scales from global to national to regional or river basin or other scales. Global scale assessments have become increasingly common as a means of informing global to national responses to pressing global environmental concerns including responding to climate change, biodiversity loss, and stratospheric ozone depletion (IPCC, 1992, 1995, 2001, 2007; MEA 2005; WMO 2007). However, many of these global environmental assessments have had limited influence on national and global responses to mitigate these and other environmental threats with ozone depletion and acid raid being notable exceptions. In contrast, regional scale assessments like the RISAs have had more success providing useful information for policymakers. RISAs have been considered a success at translating science to policy partly because they reduce barriers to information use while leveraging drivers of information use and because they reconcile the supply of and demand for science (McNie *et al.* 2005; McNie 2008).

3.3 Towards More Effective Assessments for Policy

Researchers have studied assessments in the hopes of better understanding what makes some assessments more effective than others. For example, in their study of international assessments Clark & Dickson (1999) found that more effective assessments achieve a balance of saliency, credibility and legitimacy. Saliency refers to the "perceived relevance or value of the assessment" while credibility refers to the "perceived authoritativeness…of the technical dimensions of the assessment process" to the scientific community. Lastly, legitimacy captures the "perceived fairness and openness of the assessment process" to the mostly policy or political community who might reasonably use the assessment product. Clark & Dickson (1999) reached their conclusion by considering assessments as processes in as much as specific final products. By considering the assessment process in addition to the end product, aspects of the process were found to be just as important in promoting assessment effectiveness as the relevance of the final product (Clark & Dickson 1999). Rather than focusing on the assessment process or product, others have focused on reconciling the scale of assessment with the scale of decision making (Cash 2000; Cash & Moser 2000). For example, based on findings suggesting that local level decision makers must respond to local sensitivities that manifest from global environmental threats, Cash (2000) called for a new paradigm of distributed assessments that take into account the information needs of decision makers at varying scales. Moreover, this research found that "managing boundaries between disciplines, across scales of geography and jurisdiction, and between different forms of knowledge" helps ensure trade-offs between saliency, credibility, and legitimacy are managed across disciplines, jurisdictions, and scales (Cash 2000; Cash & Moser 2000; Cash *et al.* 2002, p. 1).

While perceived saliency, credibility, and legitimacy have been found to be key attributions of more effective international assessments designed to influence aspects of the global environmental regime (Clark *et al.* 2006; Jäger & Ferrell 2006), other research have questioned whether these attributions continue to play a dominant role in determining effectiveness in the context of assessments conducted at other scales (e.g., national, regional). For example, a number of researchers have studied the National Acid Precipitation Assessment Program (NAPAP) criticizing NAPAP for being irrelevant to the policy-making process (Herrick & Jamieson 1995; Roberts 1991; Rubin *et al.* 1991) in spite of efforts to maintain credibility, saliency, and legitimacy (Keller 2009). A similar result was found in reviewing outcomes from the first United States National Assessment of the Potential Impacts of Climate Change (USNA). Political efforts to counter the impact of the assessment once completed (Mooney 2007) as well as aspects of the assessment process itself (e.g., not ongoing, budget constraints) (Morgan *et al.* 2005) proved to lessen the impact of the first USNA in spite of efforts to ensure the credibility (e.g., peer reviewed), legitimacy and saliency (e.g., stakeholder driven) of the product and process (L. Carter, personal interview, April 2, 2008; Morgan *et al.* 2005).

Factors thought to increase the effectiveness of international or national level assessments such as reconciling scales of assessment with scales of decision making, and being long-term and interactive remain important characteristics of effective regional assessments. Researchers studying regional assessments suggest assessments that are ongoing, long-term, iterative, and that match the scale of assessment with the relevant scale of decision making or management (Cash & Moser 2000; Lemos & Morehouse 2005) and that use buffering and linking strategies (Keller 2009) are more effective. Cash & Moser (2000) use scale to refer to geographic or temporally bounded phenomena or a level of organization. Matching the scale of an assessment of a particular phenomenon of interest (e.g., climate change impacts) to the scale of a potential response (e.g., water management adaptation policies) improves assessment effectiveness (Cash & Moser 2000). Lemos & Morehouse (2005) suggest to be effective, regional assessments "require a combination of knowledge-driven, applied and interactive science which strikes the delicate balance between what we need to know to understand complex problems and what stakeholders perceive to be their immediate needs for making decisions." They propose a model of interactive research and assessment, iterativity, which aims to balance interactions between stakeholders and scientists, interdisciplinarity, and usable science. The model is based on the understanding that an interdisciplinary approach and interaction with stakeholders improves the fit, usefulness, and ultimately, the usability of information resulting in increased information use (Lemos & Morehouse 2005). Thus, to be effective, assessments should maximize each iterativity component to achieve higher levels of innovation and greater societal impact (Lemos & Morehouse 2005), both indicators of more effective assessments. While most of the researchers studying assessments have approached their work using the theoretical framework of the fields of science and technology policy (STP) or science and society (STS), Keller (2009) takes a different approach using instead the framework of organizational behavior. Keller (2009) argues that science assessment organizations must jointly pursue buffering and linking strategies to increase effectiveness. Buffering strategies are those meant to protect the scientific work of the assessment from bias and politicization while linking strategies maintain ties to potential assessment information users who might rely on the outputs of science assessments to inform policy decisions (Keller 2009). While the underlying theoretical framework differs, the findings using this framework mirror that of STP and STS advanced by Sarewitz (2004) (i.e., negotiating values separately) and Lemos & Morehouse (2005) (i.e., interaction).

Integrated assessments that embrace the stakeholder process means information produced will likely be more relevant and useful. In fact, the involvement of stakeholders early on in the knowledge development process and continuing through knowledge use is thought to facilitate the usefulness of assessment information for policy and decision making. According to Brewer and Stern (2005) "research use is facilitated by formal or informal links between research and research users." Pielke (1994), Lemos & Morehouse (2005) and others report similar findings. More recent efforts have focused on improving the utility of scientific information produced by assessments by focusing on "reconciling the supply and demand of scientific information" (McNie *et al.* 2005; McNie 2007; Sarewitz & Pielke 2007). McNie *et al.* (2005) summarized results from a workshop on seven

Regional Integrated Sciences and Assessment (RISA) programs. They concluded that developing "trusting, long-term relationships with stakeholders" is a precursor to successful co-production of scientific information (McNie *et al.* 2005). In spite of this interaction component and the promise of useful, relevant information, usability is not assured.

3.4 Usable Science

To this point the literature review has focused on research that seeks to improve our understanding of how scientific assessments might be managed in such a way that assessment products are made more useful for decision makers and that the assessment itself might therefore be seen as more effective and perhaps influential. The discussion has thus far mostly ignored the distinction between useful and usable information and the ongoing debate over use-inspired science and scientific assessments between those who believe science must be kept separate from policy to maintain scientific credibility (Agrawala *et al.* 2001) perhaps, at the expense of usability, and those who argue scientists must risk other's claims of policy advocacy to make the science more usable (Oppenheimer *et al.* 2007; Pielke 2002). Instead of engaging in the latter debate, a more important focus here is to consider what characteristics of the information itself, the process of information production, or the context of information use makes information more likely to be usable. This focus will likely contribute to a better understanding of assessment effectiveness and assessment information use.

Lemos and Rood (in press) define information usefulness in terms of the "functionality and desirability" of the information. Here, information that is usable is applicable and fits the "decision-making processes and decision environments in practice" (Lemos & Rood in press). The importance of timing and applicability is echoed by Dilling (2005), who suggests that usable knowledge is not static but develops dynamically over time through interaction between scientists and potential information users. Many scholars of assessments in practice consistently point to ongoing interaction between scientists and potential information users as a critical precursor to producing usable knowledge (Lemos & Morehouse 2005) even if the process is "uncertain, uncomfortable, and discomforting"

(Udall *et al.* 2008). Producing usable information is at the heart of use-inspired research and is the crux of assessments aiming to provide relevant information for policy makers. Use-inspired science is critically important in the area of climate variability and change because of the focus on providing useful climate information for a wide range of potential users. Furthermore, in the United States, much of the Federal funding of climate science conducted by organizations like the U.S. Climate Change Science Program and the RISAs is justified by the potential value of the information for policy and decision making and for the presumed societal benefit derived from improved decision making based on climate information (NRC 2008). In the case of the RISAs, the rationale seems justified given RISAs are considered to be a model for other organizations seeking to successfully link science to policy and decision making (Feldman *et al.* 2008; Miles *et al.* 2006).

Looking beyond the way assessments are carried out, provides an opportunity to explore a wealth of literature aimed at understanding a broad number of factors that affect the development of useful information and that affect information use. Since this dissertation research is particularly concerned with water manager's use of information, the focus of the following review of information use and non-use will concentrate on the water sector. Furthermore, because this research focuses on the use of climate information, this literature review is primarily concerned with studies investigating the use of climate information.

3.4.1 Barriers to Information Use

In practice, water managers do not universally employ climate forecasts or incorporate long-term climate change impacts or tree ring reconstructions into water resources operation and planning. To better understand why this is the case, many studies have focused on information production and use across three areas: (1) the effects of improving the accuracy and reliability of the product (e.g., forecast, tool, model, etc.); (2) the effects of improving the process of climate knowledge production, translation, and transfer between scientists and information users; and, (3) understanding the context within which information is used. The first and third areas have received the most attention in the literature and have focused primarily on barriers to forecast information use.

In the United States, key barriers on the forecast product side include: perceived lack of accuracy, reliability, and credibility (Callahan *et al.* 1999; Changnon & Kunkel 1999; Hartmann *et al.* 2002; Pagano *et al.* 2001; Pulwarty & Redmond 1997; Rayner *et al.* 2005; Stern & Easterling 1999; Yarnal *et al.* 2006); lack of salience (Pagano et al. 2001; Pulwarty & Redmond 1997; Stern & Easterling 1999); timeliness of forecast production and dissemination (Callahan *et al.* 1999; Pagano *et al.* 2001) or level of usefulness/usability (Callahan *et al.* 1999; Changnon & Kunkel 1999; Rayner *et al.* 2005; Yarnal *et al.* 2006); and, excessive uncertainty (Changnon & Kunkel 1999; O'Connor et al. 2005; Pulwarty & Redmond 1997; Rayner *et al.* 2005). While early findings pointed to accuracy and reliability of forecasts as a primary barrier to information use, other evidence cautions that improvement in the accuracy and reliability of the product alone does not ensure it will be used (O'Connor *et al.* 2005; Rayner *et al.* 2005). Research on the use of tree ring reconstructions by water managers in Arizona, New Mexico, Colorado and Wyoming conducted by Rice *et al.* (2009) revealed that barriers to forecast information use also apply to climate information more generally. For example, Rice *et al.* (2009) found product barriers reported by users of tree ring reconstructions include inaccurate, unreliable, not credible, not useful, and too uncertain.

Callahan *et al.* (1999) found infrequent interaction to be a key process related barrier to information use. Key organizational or context barriers of forecast information use include: valuing routine, established practices or local knowledge (Callahan *et al.* 1999; Pagano *et al.* 2001; Pulwarty & Redmond 1997; Rayner *et al.* 2005); difficulty incorporating information (Callahan *et al.* 1999; Pulwarty & Redmond 1997; Rayner *et al.* 2005; Snover *et al.* 2003); low or no perceived risk (Callahan *et al.* 1999; O'Connor *et al.* 2005; Pagano *et al.* 2001); previous negative experience (Glantz 1982; Rogers 1995; Stern & Easterling 1999); insufficient human or financial capacity (Pagano *et al.* 2001; Snover *et al.* 2003); a culture of risk aversion (Callahan *et al.* 1999; Pagano *et al.* 2001); insufficient technical capacity (Callahan *et al.* 1999; Snover *et al.* 2003); lack of discretion (Lemos 2008; Pagano *et al.* 2001); legal issues (Pagano *et al.* 2001; Rayner *et al.* 2005); and professional background (Callahan *et al.* 1999). Rice *et al.* (2009) found difficulty incorporating information into existing decision making frameworks to be a key process barrier to water managers' use of tree ring reconstructions. Barriers to information use are summarized in Table 3.1.

Table 3.1 Summary of literature derived factors that impede information use.

Barrier Type	Variables	
Product	Not accurate and reliable	Not timely
	Not credible	Not useful; not usable
	Not salient	Excessive uncertainty
Process	Not legitimate	Infrequent interaction
	One-way communication	End-user relationship
Context	Professional background	Legal or similar
	Previous negative experience	Culture of risk aversion
	Value routine, established practices, local knowledge	Insufficient human or financial capacity
	Lack of discretion	Goundwater source
	Low or no perceived risk	System size – smaller
	Difficulty incorporating information	Insufficient technical capacity (i.e., no models)

3.4.2 Drivers of Information Use

In addition to probing barriers to information use researchers have also searched for factors that increase the likelihood of climate information use. Like the research on barriers to information use, studies on drivers of information use focus on aspects of the information product, process of information production and dissemination, and the context of information use. First, climate information products that are judged to be accurate (Changnon & Kunkel 1999; Pagano *et al.* 2002), credible (Cash *et al.* 2003), salient (Cash *et al.* 2003; Lemos & Morehouse 2005; Pagano *et al.* 2002; Pulwarty & Redmond 1997; Stern & Easterling 1999; Wilbanks & Kates 1999), useful (Changnon & Kunkel 1999; Lemos & Morehouse 2005; Pagano *et al.* 2002; Snover *et al.* 2003; Wilbanks & Kates 1999), and timely (Lemos & Morehouse 2005; Pagano *et al.* 2002; Stern & Easterling 1999) are more likely to be used. Aspects of the process of information production and dissemination found to promote information use include: perceived legitimacy of the process (Cash *et al.* 2003; Lemos & Morehouse 2005); two-way communication (Carbone & Dow 2005; Lemos & Morehouse 2005; Pagano *et al.* 2002); iterativity, trust, and co-production (Lemos & Morehouse 2005); and, establishing a long-term relationship (Lemos & Morehouse 2005; Pagano *et al.* 2001; Rayner *et al.* 2005).

The context within which information is used is also important. For example, previous positive experience with innovation causes managers to view potential new innovations positively thus increasing the likelihood of climate information use (Glantz 1982; Lemos 2008; Pagano *et al.* 2001). Increased risk of impacts from climatic events and triggering events such as a severe drought can increase the use of climate information (Callahan *et al.* 1999; Hartmann *et al.* 2002; O'Connor *et al.* 2005; Pagano *et al.* 2001; Rice *et al.* 2009; Schwarz & Dillard 1990; Yarnal *et al.* 2006). Public pressure or the threat of a public outcry against water managers for not taking climate information into account as well as the perception of vulnerability (Carbone & Dow 2005; O'Connor *et al.* 2005; Pagano *et al.* 2001) or actual physical water scarcity (Rice *et al.* 2009) can overcome the aversion to using novel information. Organizations with in-house relevant expertise or access to external relevant expertise are more likely to use climate forecasts (Pagano *et al.* 2001) as are organizations with sufficient human or technical capacity, a more flexible decision making framework, and technocratic insulation in decision making (Lemos 2008). Also, the easier it is to incorporate information into existing decision making processes, the more likely information will be used (Carbone & Dow 2005; Hartmann *et al.* 2002; Pagano *et al.* 2001). Lastly, there is some evidence that larger, surface water dominant systems are more likely to use climate information (Yarnal *et al.* 2006) than smaller, groundwater dominant systems. A summary of the drivers of information use is shown in Table 3.2.

Table 3.2 Summary of literature derived factors that drive information use.

Driver Type	**Variables**	
Product	Accurate and reliable Credible Salient	Timely Useful; usable
Process	Legitimate Two-way communication Iterative	Trust Long-term relationship Co-production
Context	Youthful; new employee Previous positive experience Perception of climatic vulnerability In-house expertise Surface water source More flexible decision framework Triggering event (e.g., drought, El Niño)	Ease incorporating info Technocratic insulation Threat of public outcry; public pressure Water scarcity System size – larger Sufficient human or technical capacity

3.4.3 Usable Climate Information: Identify Vulnerability, Build Resilience?

Research in the area of climate variability and change holds great potential to inform policy and decision makers not only about exposure and sensitivity to climatic risks but also to help reduce those climatic vulnerabilities and to build resilience. Global climate assessments like that produced by the Intergovernmental Panel on Climate Change (IPCC) carefully articulate the risk of climatic change to policy makers (IPCC 2007). Similarly, the first USNA aimed to identify risks posed by climate variability and change focused on the United States (NAST 2000). At a more localized level, regional assessments like the RISAs aim to provide actionable information about potential climate change impacts to regional and local decision makers. RISAs also contribute to USNA efforts. For example, RISAs in the Pacific Northwest and in the Southwest United States, the two RISAs that are the focus of this research, supported the first USNA (e.g., Sprigg & Hinkley 2000) and subsequently contributed to more localized assessment efforts (e.g., Bales *et al.* 2004). While it is clear assessments help identify potential impacts and risks, what is less clear is whether or not that information is used to build resilience to the risks posed by climate variability and change over the longer term.

For the science generated through the climate assessment process to be useful for building resilience, the information must be integrated into policy and decision making such that actions taken ultimately improve resilience. Resilience refers to the "magnitude of disturbance that can be absorbed" before a system changes state and the "capacity for adaptation to emerging conditions" (Adger 2006). Systems seek to buffer against perturbations to minimize their impact to prevent crises from overwhelming their capacity to respond (Berkes & Folke 2000; Gunderson *et al.* 2002). Building resilience is one strategy to buffer against disturbances to the management and/or natural system originating from vulnerabilities to climate risks. In the case of water resource systems, vulnerabilities might arise from changes in the timing or availability of water or to longer and more severe droughts than have been experienced in the past or to climate related increases in demand. Natural climatic variability has long required water managers to institute buffers against the threat of too little or too much water. Water managers have buffered against this natural climatic variability through the use of structural (e.g., dams, levees, etc.) and more recently non-structural (e.g., conservation) measures. But the threat of climate change, increasing competition for water supplies, and increasing climate variability are collectively pushing water managers to consider new limits beyond what they have experienced in the past. Thus, there is the potential for water managers to use climate assessment information or other climate information to quantify these new limits and to inform a range of potential responses to buffer against these new collective perturbations to water resources.

Water management organizations build resilience by identifying and addressing potential vulnerabilities through planned demand and supply management activities and by potential operational changes. Building resilience through planning activities is a key response identified by Somers (2009). However, it is also possible other organizational behaviors can increase resilience potential. Somers (2009) suggests certain characteristics of organizations are indicative of resilience potential including organizations that: perceive environmental risk, seeking information about the environmental risk, engage in balanced decentralization, and plan. That is, organizations that have resilience potential may be better able to withstand perturbations because they better understand the risk and are potentially more prepared to respond to the risk. Researchers have begun examining the role of science generally and climate science in particular in building resilience. For example, Serrat-Capdevila *et al.* (2009) found that the collaborative development of a decision-support system contributed to increasing resilience potential in the San Pedro Basin in Arizona-Sonora among participants in the Upper San Pedro Basin Partnership (USPBP). The authors argue that the USPBP has increased resilience but the evidence points to instead increasing resilience potential. Rather than building resilience, they found that the collaborative process fostered in the USPBP process increased the resilience potential in the basin by building trust and establishing a functioning network between individuals and organizations that comprise the USPBP (Serrat-Capdevila *et al.* 2009). In Southern Africa, Dilley (2004) found the use of climate information helped improve preparedness and reduce vulnerability to drought. While his focus was on the use of forecasts to reduce drought risk, the research described how decisions made as a result of perceived risk of drought increased societal resilience. In Brazil, Engle and Lemos (2010) advance our understanding of how governance indicators are associated with building adaptive capacity in 18 river basins. Their analysis suggests a positive association between integrated water governance mechanisms (e.g., representation, participation, networks) including knowledge use and adaptive capacity (p. 8). While these and other studies point to progress improving our understanding of the use of science to build resilience, there is a need to better understand how climate information generated through local, regional, or national assessments may help build resilience to climate variability and change for the water sector and other sectors.

3.5 Boundary Organizations and Knowledge-Action Systems

The change in the social contract/linear model construct towards a model of co-production together with the press to deliver more socially relevant and beneficial information has fostered the development of boundary organizations that reflect knowledge gleaned about barriers and drivers of information use oriented to providing useful information to aid decision makers. In fact, there is a movement towards the creation of knowledge-action systems (Cash *et al.* 2003), wherein knowledge to inform decisions is marshaled to information users through concerted boundary management efforts as part of a knowledge-action system. These boundary management efforts are moving increasingly into the hands of boundary organizations since these organizations more effectively communicate, mediate, and translate the science for decision makers (Cash *et al.* 2003), routinize boundary spanning activities, and fill a need left by institutions that lack the means or motivation to conduct boundary spanning functions themselves (Buizer *et al.* 2010). Boundary organizations' adept management of the process of knowledge creation to use helps "ensure the stability of the knowledge system in a changing political, economic, and climatic context" (Buizer *et al.* 2010).

Knowledge action systems were conceived to bolster the translation of useful information to meet the goals of sustainable development (Cash *et al.* 2003). The concept has since expanded to include other potentially productive areas such as developing knowledge systems to support decision making related to global health concerns and to support the use of climate forecasts in agriculture, water resources, and other natural resource sectors. For example, van Kerkhoff & Szlezak (2010) examined how The Global Fund to Fight AIDS, Tuberculosis, and Malaria contributes to a knowledge-action system to aid in the global response around important diseases. Buizer *et al.* (2010) extended the application of knowledge action systems to investigate how such systems support climate forecast use by farmers in Australia, water managers in Hawaii, and natural resource managers in the Columbia River Basin. Knowledge-action systems focused on providing climate forecasts (and perhaps other climate information) for water managers seems to be a natural extension on previous work studying water managers' use of forecasts and other climate information. The first paper to study water managers' use of forecasts using the concept of knowledge-action systems was recently published by Jacobs *et al.* (2010). The research examined information use by water managers in Brazil, Thailand, Mexico, and the U.S. focusing more on the need for facilitating participatory governance processes rather than fully exploring knowledge-action systems, which go beyond participatory governance, in theory or practice. Improving our understanding of how knowledge-action systems might aid policy and decision makers in the area of water resources management appears ripe for further exploration and contribution.

Chapter 4

Methodology

To take advantage of the strengths of both qualitative and quantitative methods a mixed method approach is used for this study. Using qualitative survey data to inform and enhance the quantitative survey data and using survey data to broaden results from less extensive interview data is preferred over using a single methodological approach (Miles & Huberman 1994). I collected qualitative data through semi-structured interviews and quantitative data through surveys.

4.1 Interviews

I conducted 38 semi-structured, key informant interviews with water managers from the Pacific Northwest (PNW) and the Southwest (SW) during the winter and summer of 2009. The interviewees were selected from a database of client contacts provided by the Climate Impacts Group (CIG) in the PNW and the Climate Assessment for the Southwest (CLIMAS) in the SW. Conversations with RISA Principle Investigators (PIs) and Program Managers (PMs) over a period of several months during 2008 enabled and facilitated access to the identified RISA stakeholders for the purposes of this research. These conversations also helped elucidate the history of the RISA, their research approach, and their approach to working with information clients.

The selection of the interviewees was informed by conversations with RISA PIs and PMs. First, interviewees were chosen only if they were familiar to the RISA PI or PM. A threshold level of familiarity was taken as evidence that the interviewee had some history with the RISAs. This familiarity enabled the PI or PM to confirm the client was a suitable choice for the project because of their involvement in water resource management. While the first criterion was familiarity, the second criterion was involvement in the water sector. The preference for water sector clients was necessary because potential interviews were selected from a much larger database of RISA clients representing the range of RISA research areas. These criteria helped narrow the focus of the investigation to water managers from utilities and state, county, and local governmental agencies that had some level of experience with or knowledge of the RISAs. Selecting the interviewees in this way provided a means to gather data about RISA information use by water utilities involved in municipal water supply as well as local, county, and state level water managers involved in water resource allocation, management and planning. Ultimately, the selection of interviewees enabled comparisons across states, between RISAs, and among groups of respondents. The interviews were conducted by telephone and averaged 58 minutes.

The research was carried out in stages starting with the literature review then development and testing of an interview protocol, interviewee background research, conducting the interviews, draft interview notes preparation and review, and transcript preparation. Coding and analysis began after the interviews were completed, starting with transcript coding of “information use” using NVivo (QSR International software 8.0) and case selection followed by qualitative analysis and development of case descriptions, group descriptions, and final analysis. A second batch of coding of factors affecting information use was also completed and analyzed both qualitatively and quantitatively. Figure 4.1 depicts the steps involved in the research design and implementation for the interview portion of the study.

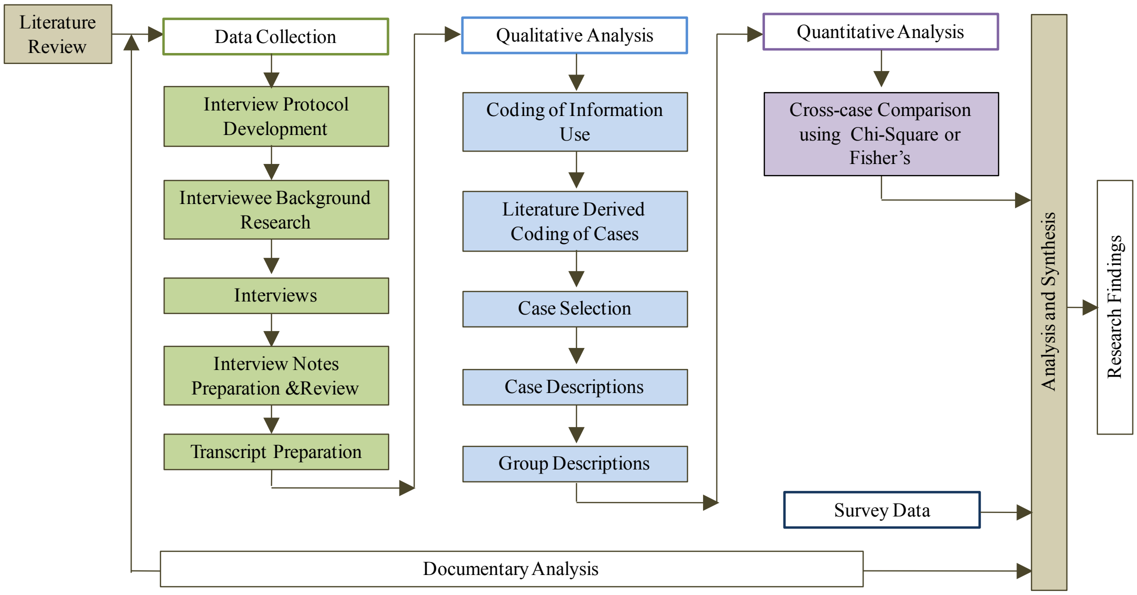


Figure 4.1 Interview data collection and analysis.

The semi-structured interview was designed to ensure each interviewee was asked the same questions and to facilitate making comparisons across groups and respondents (Berry 2002; Hochschild 2007). The literature review on barriers and drivers of information use, science to policy models, RISAs, and decision making informed the development of the interview protocol. However, the interview instrument remained broad in approach, aimed at understanding five topic areas: (1) the individual's professional background and experience; (2) major issues and concerns for the individual's organization; (3) interactions between the individual and/or the organization and the RISA(s); (4) if and to what extent the individual or organization used RISA generated climate information or other climate information; and, (5) individual and/or organizational decision making related to the use of climate information. The interview instrument was pilot tested to ensure clarity of the questions and appropriateness of measures.

In accordance with best practices for key informant interviews, preparations preceding the interview included research on the interviewee's organization and the interviewee himself or herself (Berry 2002; Hochschild 2007; Yeung 1995). This preparatory background research included identification of materials and presentations authored or co-authored by the interviewee or about the interviewee or organization and information about the organization itself such as size, location, structure, fit within a larger institutional context, and authority. This background information provided a foundational understanding before any questions were asked helping to ensure a more thorough interview. Furthermore, the background information assisted in triangulating responses from each interviewee and among interviewees (Yeung 1995). Table 4.1 provides a summary of the interviewees' RISA region and broad affiliation.

Table 4.1 Water sector interviewees by RISA, region, and affiliation.

	RISA	CIG	CLIMAS	
	Region	PNW	SW	Total
Governmental		9	8	17
Utility/municipal water supplier		7	9	16
Other		0	5	5
	Total	16	22	38

Note taking during the interview helped track responses and thematic insights that emerged during the conversation. Notes were shared with each interviewee as a check to ensure the topics discussed were accurately reflected in the notes. Some interviewees suggested a few minor changes of fact; some suggested none, and a few provided additional details to clarify the notes. All suggested changes were reviewed and additions and factual corrections were incorporated into the final version of the interview notes. In addition to the notes, a complete transcript of each interview was prepared at the completion of the interview (Figure 4.1).

4.1.1 Interview Data Analysis

The transcript and notes were qualitatively analyzed using NVivo (QSR International software 8.0) to first determine if any RISA information was used by the interviewee. To make this determination all 38 interviewee notes and transcripts were coded using free nodes to capture examples of the range of information use. The intent of using free nodes was to allow an inclusive definition of "information use" rather than a narrower, predefined definition of "information use." The more inclusive definition was bounded on one end by no use and on the other end by extensive and sustained use. Examples included information used for: informational or referential purposes, long-term planning, and to guide built infrastructure decision making for new projects. A codebook was developed that included each free node along with representative information use examples and any relevant exclusions or exceptions. The codebook formalized the coding procedure and provided a means to systematically determine how to group cases such that comparisons could be made across cases wherein RISA information was used and between cases where information was used or not used.

Once coding revealed which cases used RISA information and which cases did not, the next step in the analysis involved analyzing the notes and transcripts to extract common themes and factors that inhibited or fostered RISA information use. The literature on drivers of and barriers to information use served as the theoretical framework for organizing and analyzing the data obtained through the interviews. Results from the coding were used both qualitatively to gain a deeper understanding about why water managers used information and quantitatively to compare across grouped cases (e.g., utilities vs. governmental water managers, PNW vs. SW). The quantitative analysis of factors affecting information use by interviewee affiliation and RISA region was performed using SPSS (SPSS Statistical software 17.0). This information was particularly useful in guiding the development of the survey instrument and subsequent analysis of survey data.

Next, a closer examination of the cases wherein RISA information was used commenced. This step involved qualitatively analyzing the notes and transcripts to discover concepts, themes, and patterns of information use to develop initial models of: (1) how information is used to inform decisions within organizations and (2) how RISAs work across organizations and scales to provide information and affect change. The first step in looking within organizations was to identify emergent themes and patterns among (i.e., within all utilities or within all governmental agencies) and between groups of cases (i.e., between utilities and governmental agencies). This process involved first developing individual descriptions for each case where each case is a single interview. The individual case descriptions captured: the characteristics of the interviewee's organization; the organization's "end goal" or ultimate water management priority; what information was used; how that information was used; what limited or facilitated that use; and, the organization's decision making authority, structure, and decision making process. The final piece of each case description focused on developing categories of decisions made by water managers using RISA information. Once individual case descriptions were completed, group descriptions were initiated wherein one-on-one interviews with water managers grouped together for analysis. Groups were formed for all utility water managers, for all state, county or federal agencies, and for regions comprised of states, utilities, and agencies. The goal of preparing group descriptions was to capture how sets of cases were both similar to and different from each other (Ryan 2007). This work enabled the extraction of common themes and patterns of information use across groups of cases that could then feed into a conceptual model of information use.

The last step of the interviewee analysis involved extensive documentary review to supplement information gleaned from the interviews with other data about state, county, and local water management and planning for each state. A documentary review focused on compiling information about: water availability, allocation, and use for each state; water resource stressors including climate variability, climate change, and growth; water laws; and, existing or proposed assessment and planning at the local, county, and state levels to help alleviate current and anticipated water resource stressors. The documentary review served as a supplement to the interviews. Together both information sources helped inform the role of RISAs and information use in actions taken to alleviate stressors and helped inform a model of how RISAs work across organizations to provide information and affect change.

4.2 Surveys

In addition to interviews with RISA clients, a survey was developed and administered across the two RISA regions tailored to each state: Arizona, Idaho, New Mexico, Oregon, and Washington. A review of the literature and preliminary results from the interviews were used to inform the development of the survey instrument and subsequent variable selection and interpretation for a logistic regression performed on the survey data using SPSS (SPSS Statistical software 17.0). During survey development, the survey instrument was reviewed by RISA scientists familiar with water systems and water resource stressors in their respective regions. After obtaining input and review from the RISA PMs and PIs, the survey instrument was pilot tested during a two-week period in February 2009. Pilot testing with water managers helped ensure clarity of the questions and appropriateness of measures. The water managers providing feedback in the pilot study were not included in the survey sample.

Several design choices were made during the development of the survey instrument. First, "no opinion" or "don't know" options were excluded from response categories to reduce the likelihood of respondent satisficing, whereby respondents select "don't know/no opinion" even when the individual has an opinion, as a way of completing the survey with minimal effort (Krosnick 1991). Excluding these categories is thought to allow for the collection of more valid and informative data (Krosnick *et al.* 2002). The trade-off is that respondents must exert more effort to complete the survey and may be frustrated by the lack of "no opinion" and "don't know" options which could result in lower rates of survey completion. Satisficing also applies when questions contain long lists, as respondents tend to seek satisfactory responses rather than optimal responses. These tendencies create primacy effects whereby choices that are encountered first are more often selected (Krosnick & Alwin 1987). To reduce satisficing and primacy effects questions with long lists were substantially reduced. A second design choice excluded rank order type questions. This design choice reduced the overall difficulty and time of response but did sacrifice some potentially useful information for the sake of potentially more responses (Converse and Presser 1986). Third, Likert scaled questions used balanced scales (e.g., equal numbers of positive and negative response choices) to avoid biasing the respondents in a particular direction (Brace 2004). Also, shorter scales were chosen to reduce the time required per question (Preston & Colman 2000) with the trade-off being that it was more difficult to minimize contraction bias, or clustering of responses in the middle (Tourangeau *et al.* 2000). Lastly, more forced choice, closedended questions were used rather than open-ended questions to reduce ambiguity of response and simplify analysis (Converse & Presser 1986). In general, the survey was kept as short as feasible without being “too short to be taken seriously” (Fife-Schaw 2006).

The survey was administered to 2,645 water managers at Community Water Systems (CWS) across Arizona, Idaho, New Mexico, Oregon, and Washington via the Web using Qualtrics (Qualtrics, Inc. survey software 2008) and through the mail from March to April 2009. CWSs are public water systems that supply water to at least 25 residents year-round (EPA 2009). The survey contained a mix of open- and close-ended questions covering a range of topics including: issues of concern, water system operation and planning, information use, and collaboration with research and other organizations.

The survey administration effort followed a modified Dillman (1978) Total Design Method (TDM) which optimizes response rates (Dillman 1991) using multiple contacts with potential respondents to increase response rates for mailed surveys (Rada 2005). A full TDM approach was not feasible within the limited research budget. The modified approach incorporated a prenotification letter, survey mailing, and follow-up postcard because research indicates a prenotification letter and follow-up reminder are the most productive contact strategies resulting in the greatest impact on response rates (Dillman 2007). This approach allowed for cost savings without unduly undermining participation. The survey instrument and contact letters were also crafted to maximize response rates. A high-contrast cover page with a neutral graphic was used with each CWS mailed survey. The use of a likeable cover, with a simple, neutral graphic design or design with a high contrast has been shown to increase response rates (Gendall 2005; Nederhoff 1988). Lastly, a small incentive – a chance to win a water management text worth up to $100 - was used to encourage potential survey respondents to complete the survey. Incentives have been shown to increase response rates (James & Bolstein 1990). In the end, the inducement was likely not all that effective as those who “won” the inducement mostly responded by saying they were happy to support the research effort and donated the money to the project. Figure 4.2 shows the research design for collection, management, and analysis of the survey data.

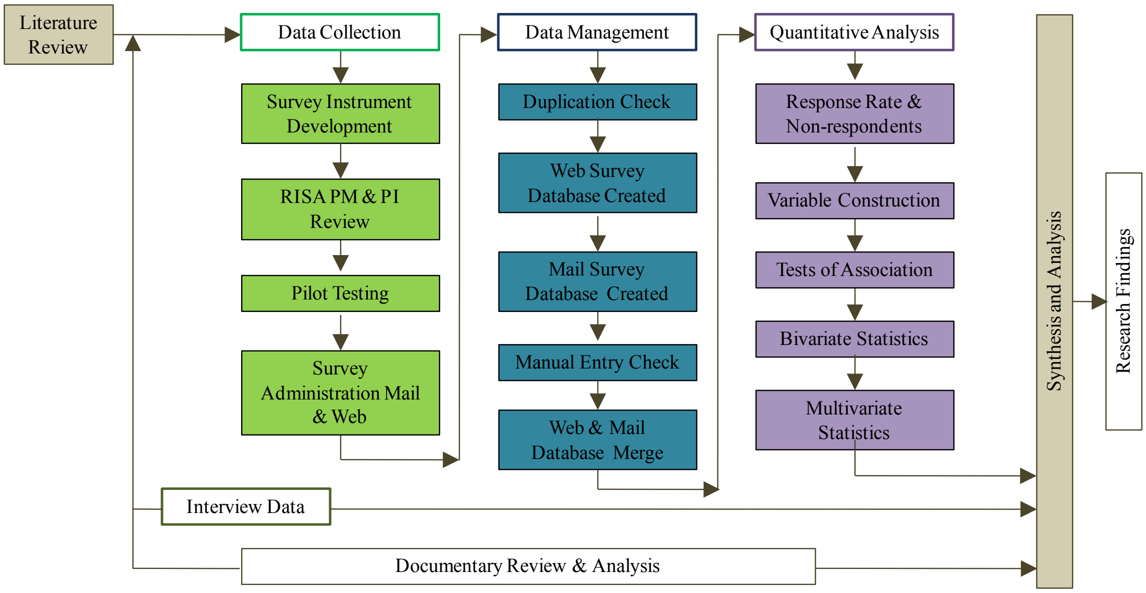


Figure 4.2 Survey research design: data collection, management, and analysis.

Survey data were collected via electronic and mailed surveys. Studies have examined response rates of email and paper surveys and found mailed surveys to have higher response rates than email surveys. However, web based surveys offer significant cost and time savings from reduced copying and postage costs to significantly reduced time for raw data entry. It was expected that water managers from CWSs would respond using the mailed survey consistent with studies that indicate respondents who are older or professional generally respond better to mailed surveys (Kaplowitz *et al.* 2004; Shih & Fan 2008). As expected, the majority of respondents chose to respond via the mailed survey (79%) rather than the online survey (21%). Online data were downloaded directly into SPSS for analysis. Data from mail based hard-copy surveys were entered manually into two separate databases by different individuals. These two databases were then compared using SAS (SAS/STAT Software by SAS Analytics 9.2) and any discrepancies were corrected by comparing the data entry to the hardcopy survey. To ensure no duplicate entries were entered online and mailed survey identification numbers were cross-checked against a master database. Once this step was completed, the web and mail survey data were merged into a single SPSS database for each state. The research design for data management is depicted in Figure 4.2 along with the steps used in survey development and final analysis.

4.2.1 Survey Data Analysis

A state by state analysis of survey respondents versus non-respondents was conducted using two variables: population served, as an indicator of system size, and primary water source, as an indicator of whether or not the system relied primarily on groundwater or surface water. The analysis was conducted to assess the representativeness of the respondents to the population of water managers in the PNW and SW. If respondents were not representative of the population of water managers either based on system size or water source, then responses from the over-sampled respondents might require appropriate weighting to better account for the population of water managers. The need for weighting is determined by the comparison between respondents and non-respondents and the significance of the two variables – population served and water source – in the subsequent analysis. If population and water source are not significant in the analysis, then weighting of the potentially oversampled groups is likely not necessary. Population size and water source are reasonable measures to use for this evaluation given there are thought to be differences in information use due to size and water source. Ideally, additional variables would have factored into this analysis of representativeness; but, unfortunately, no other variables spanning the entire surveyed population including respondents and non-respondents were available.

The research was carried out in stages starting with the literature review, development and testing of an interview protocol, and then conducting the interviews. The survey instrument design and testing process was begun during the interview data collection period and preliminary analysis. Thus, interview data served to inform survey development and subsequent data analysis. Documentary analysis was ongoing throughout the process informing both survey design and analysis. Analysis of the survey data was conducted once the survey return period expired and data management was completed. Figure 4.2, shown previously, depicts all of the steps involved in the survey used for this research.

4.2.2 Variable Construction

4.2.2.1 The Dependent Variable

For the interviews, *RISA Use* captured a range of intensity of use or interaction from the most basic – attending a conference or presentation or exchanging information emails - to the most advanced, comprised of contracting with the RISA to meet specific individual or organization informational needs. Answers to two interview questions (IQ) provided the necessary data to evaluate RISA use for each interviewee:

> *IQ-1 Please tell me a little bit about your experiences interacting or collaborating with (insert CLIMAS or CIG) or other research organizations.*
> *IQ-2 Can you tell me a little bit about how your organization is addressing climate variability and climate change and what facilitates or hinders your actions? Please provide examples.*

While responses to the above questions elicited descriptions of a range of information use, these uses were collapsed into a dichotomous variable where "yes" used RISA information =1 or "no" did not use RISA information =0 for each interviewee.

Creating the dependent variable for the survey data followed a similar procedure. For the PNW data, the dependent variable was use of CIG as a climate or general information source or collaborating with CIG. The dichotomous measure was constructed from responses to three survey questions (SQ) listed in Table 4.2.

Table 4.2 Survey questions (SQ) used to construct *RISA Use* for the Climate Impacts Group.

SQ-1	How much do you collaborate with the Climate Impacts Group at the University of Washington?
SQ-2	Mark the information sources you most often use to assist you with managing your system or for general information (with the Climate Impacts Group, University of Washington as one potential information source).
SQ-3	Mark the information sources you most often use for weather or climate information (for example, precipitation, temperature, flooding, drought, reservoir levels, climate change, tree ring reconstructions, etc.) (with the Climate Impacts Group, University of Washington as one potential information source).

The first question about collaboration with CIG was an ordinal measure with five levels, while the second and third questions were dichotomous yes/no questions. Responses to the first question: How much do you collaborate with the Climate Impacts Group?" were collapsed into dichotomous yes/no responses with "a lot", "some", and "a little bit" coded as "yes" and assigned a value =1 while "none" or "never heard of organization" were assigned a value of 0. Once the ordinal data were converted to a nominal measure, responses to the three questions were combined. A "yes" response to any of the three questions was considered an indication of a system's use of CIG and was coded as 1 in the construction of the dichotomous dependent variable *CIG Use*. All other responses were coded "no" or 0.

For the SW data, the dependent variable was use of CLIMAS as a climate or general information source, use of the Southwest Climate Outlook (SCO), or collaborating with CLIMAS. The SCO is a monthly climate forecast publication produced and distributed by CLIMAS. The measure for use of CLIMAS was constructed from responses to five survey questions listed in Table 4.3.

Table 4.3 Survey questions (SQ) used to construct *RISA Use* for the Climate Impacts of the Southwest.

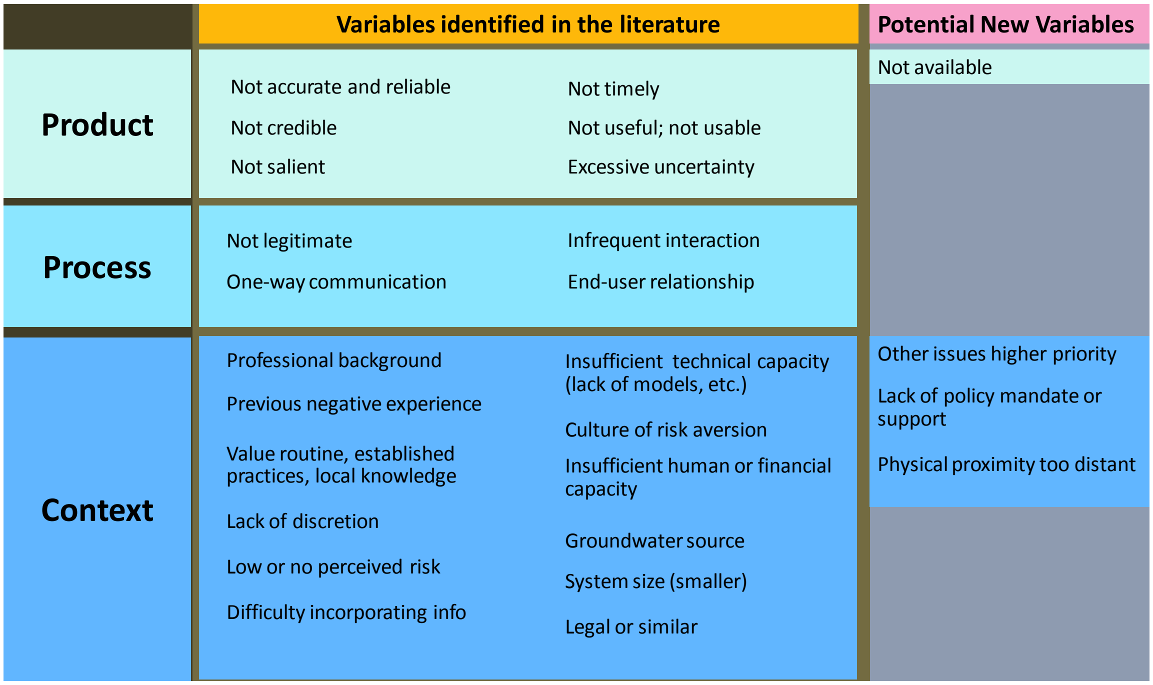
SQ-4	How much do you collaborate with the Climate Impacts of the Southwest at the University of Arizona?
SQ-5	Mark the information sources you most often use to assist you with managing your system or for general information with the Climate Impacts of the Southwest as one potential information source.
SQ-6	Mark the information sources you most often use for weather or climate information (for example, precipitation, temperature, flooding, drought, reservoir levels, climate change, tree ring reconstructions, etc.) with the Climate Impacts of the Southwest as one potential information source.
SQ-7	Mark the information sources you most often use to assist you with managing your system or for general information with the Southwest Climate Outlook as one potential information source.
SQ-8	Mark the information sources you most often use for weather or climate information (for example, precipitation, temperature, flooding, drought, reservoir levels, climate change, tree ring reconstructions, etc.) with the Southwest Climate Outlook as one potential information source.

Again, the first question about collaboration with CLIMAS was an ordinal measure with five levels while the second thru fifth questions were dichotomous, yes/no questions. Responses to the first question: How much do you collaborate with the Climate Assessment for the Southwest?" were collapsed into dichotomous yes/no responses with "a lot", "some", and "a little bit" coded as "yes" and assigned a value = 1 while "none" or "never heard of organization" were assigned a value = 0. Once the ordinal data were converted to a nominal measure, responses to the five questions were combined. A "yes" response to any of the five questions was considered an indication of a system's use of CLIMAS and was coded 1 to construct the dichotomous dependent variable *CLIMAS Use*. All other responses were coded 0 for no RISA use. *CIG Use* and *CLIMAS Use* were combined into the dichotomous dependent variable *RISA Use*.

4.2.2.2 Independent Variables from the Interviews

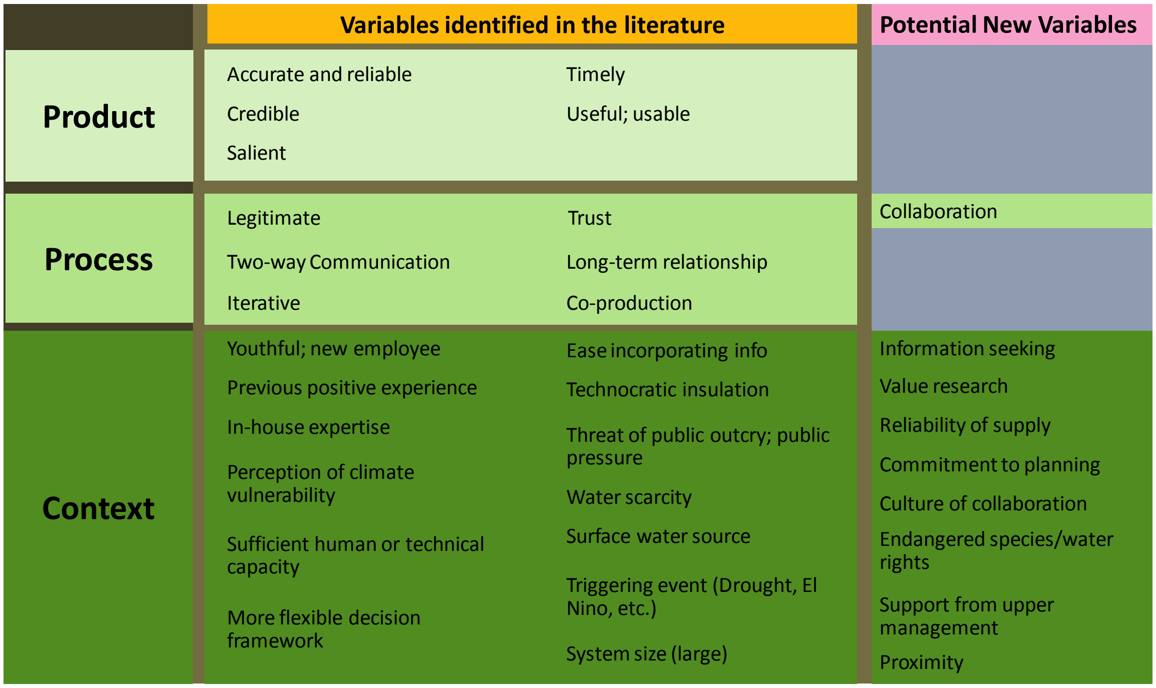
Factors identified in the literature on drivers of and barriers to information use provided the theoretical framework for analyzing the interview data (See Literature Review). Figures 4.3 and 4.4 summarize the factors used in interview coding. In both figures the left most column serves as the row heading dividing the figure into rows of product-, process-, and context barriers (Figure 4.3) or drivers (Figure 4.4). The large middle column in both figures identifies those product, process, and context variables identified in the literature. The right most column, lists the potential new variables identified through coding of the interview data.

The factors summarized in Figures 4.3 and 4.4 were used in the NVivo (QSR International software NVivo 8.0) content analysis. Notes from each interview were subjected to a thorough analysis to identify and select exact words and word phrases corresponding to the product, process, and context barriers and drivers of information use identified in the literature. Additional variables not identified in the literature but which appeared to contribute to or impede information use were identified during the coding process and coded as free nodes. Free node variables helped capture the full suite of product, process, and context barriers to and drivers of RISA information use.



	Variables identified in the literature		Potential New Variables
Product	Not accurate and reliable Not credible Not salient	Not timely Not useful; not usable Excessive uncertainty	Not available
Process	Not legitimate One-way communication	Infrequent interaction End-user relationship	
Context	Professional background Previous negative experience Value routine, established practices, local knowledge Lack of discretion Low or no perceived risk Difficulty incorporating info	Insufficient technical capacity (lack of models, etc.) Culture of risk aversion Insufficient human or financial capacity Groundwater source System size (smaller) Legal or similar	Other issues higher priority Lack of policy mandate or support Physical proximity too distant

Figure 4.3 Variables identified in the literature as barriers to information use and through free node coding that are potential barriers to information use.



	Variables identified in the literature		Potential New Variables
Product	Accurate and reliable Credible Salient	Timely Useful; usable	
Process	Legitimate Two-way Communication Iterative	Trust Long-term relationship Co-production	Collaboration
Context	Youthful; new employee Previous positive experience In-house expertise Perception of climate vulnerability Sufficient human or technical capacity More flexible decision framework	Ease incorporating info Technocratic insulation Threat of public outcry; public pressure Water scarcity Surface water source Triggering event (Drought, El Nino, etc.) System size (large)	Information seeking Value research Reliability of supply Commitment to planning Culture of collaboration Endangered species/water rights Support from upper management Proximity

Figure 4.4 Variables identified in the literature as drivers to information use and through free node coding that are potential drivers to information use.

4.2.2.3 Independent Variables for the Surveys

The literature on factors that drive or inhibit information use and preliminary results from the interviews informed creation of the survey questions and variable construction. Unfortunately, product and process factors were more difficult to obtain from a larger population of water managers who might not interact with RISAs or use RISA information. To reach more water managers and ensure a large enough sample size the survey instrument had to be kept as brief as possible since longer surveys generally result in lower response rates (Bogen 1996; Dillman *et al.* 1992; Yammarino *et al.* 1991). Also, preliminary results from the interviews underscored the importance of understanding context factors among RISA users and the broader population of water managers in addition to any product or process factors. For these reasons, fewer product or process questions were included than questions targeted towards eliciting context factors that drove or impeded RISA information use.

4.2.2.3.1 Construction of Product Variables

Three questions were used to collect information about barriers that impede use of three categories of climate information: forecasts, tree rings or climate proxies, and climate change information. First, water managers were queried about whether or not they used each category of climate information - forecasts, tree rings or climate proxies, or climate change impacts or scenarios information. Answers to the first part of the information use questions formed three separate variables. Water managers that answered the information use questions in the affirmative were instructed to skip the follow-up question asking why climate information was not used. Water managers who answered "no" to a climate information use question were asked a follow-up question. The three follow-up questions were:

> *SQ-9* *We do not use forecasts or similar information because the information is…?*
>
> *SQ-10* *We do not use tree rings or similar data because the information is…?*
>
> *SQ-11* *We do not use climate change scenarios or other climate change impacts information because the information is…?*

Each question was followed by four responses: not available for my system; too uncertain; unreliable; and, other with a blank space for a write-in response. Respondents were instructed to check all that apply. Categorical responses were summed to obtain frequencies across the four response categories for each question.

4.2.2.3.2 Process Factors and Variable Construction

Frequency of interaction is an important factor affecting information use. To obtain information about CWSs interaction with RISAs, each respondent was asked about their collaboration with a number of organizations including with the Climate Impacts Group for respondents in the PNW or with the Climate Impacts of the Southwest for respondents in the SW. An illustrative survey question asking about RISA interaction pertaining to the Climate Impacts Group is as follows:

> *SQ-12 Understanding how often CWSs collaborate with research or other organizations is very important. How much do you collaborate with the Climate Impacts Group?*

A similarly phrased question regarding CLIMAS was asked of respondents from the SW. Respondents were asked to mark the amount of collaboration they engaged in with the RISA using a scale that ranged from “a lot,” “some,” “a little bit” to “none” or “never heard of organization.” The rank ordered responses were collapsed into a dichotomous measure where a value of 1 meant collaborated “a lot,” “some” or a little bit” and a value of “0” meant did not collaborate with the RISA.

4.2.2.3.3 Context Factors and Variable Construction

Population Served, Budget, and *Primary Water Source*

Two variables - *primary water source* and *population served*, a demographic variable – were obtained not from the survey but separately from the U.S. Environmental Protection Agency’s Safe Drinking Water Information System database through Freedom of Information Act requests and from state drinking water department websites. The dataset containing water source and population served information was later merged into the survey results database using water system name as the key identifier between datasets.

CWSs rely on surface water or groundwater for which they have water rights or permits. Alternatively, CWSs may purchase water from other systems. *Primary water source* was constructed from information obtained from the states or EPA to create a three-category nominal variable with “1 = groundwater,” “2 = surface water,” and “3= other” (e.g., purchased water, etc.). In both the PNW and SW most CWSs are small, groundwater-based systems. Also, the largest systems in both regions are generally surface water systems. This pattern of small groundwater and large surface water systems is typical throughout the United States.

Population served is a good approximation of system size, because larger systems generally serve more people. To confirm this assumption I computed a test of association between log transformed *population served* and CWS *budget*. The variable *budget* reflects self-reported CWS budget obtained from a survey question asking for a system's approximate total yearly budget including operation, maintenance, and planning. *Budget* is an ordinal variable with six categories ranging from <$25,000 to >$20 million.

Distance, Information Sources, and *University Collaboration*

In both regions the variable *distance*, used as an indicator of RISA accessibility, was calculated as the Euclidean distance between the physical address of the RISA and the physical address of the CWS. This RISA required first geocoding the address of both RISAs and the address or post office box of all CWSs responding to the survey using ArcGIS (ESRI software ArcGIS 9.2). Geolocating is a procedure that uses geographic information systems to determine the latitude and longitude of a location within a coordinate system. Both RISAs and 49.6% of survey respondents were geocoded to the exact street address and 50.4% were geocoded to the center of the zipcode associated with each respective post office box location. Distance from each CWS to the corresponding regional RISA was calculated as the straight line (Euclidean) distance between the two geolocations. The distance is measured in miles. Geocoded locations for the PNW and SW are shown in Figures 4.5 and 4.6, respectively.

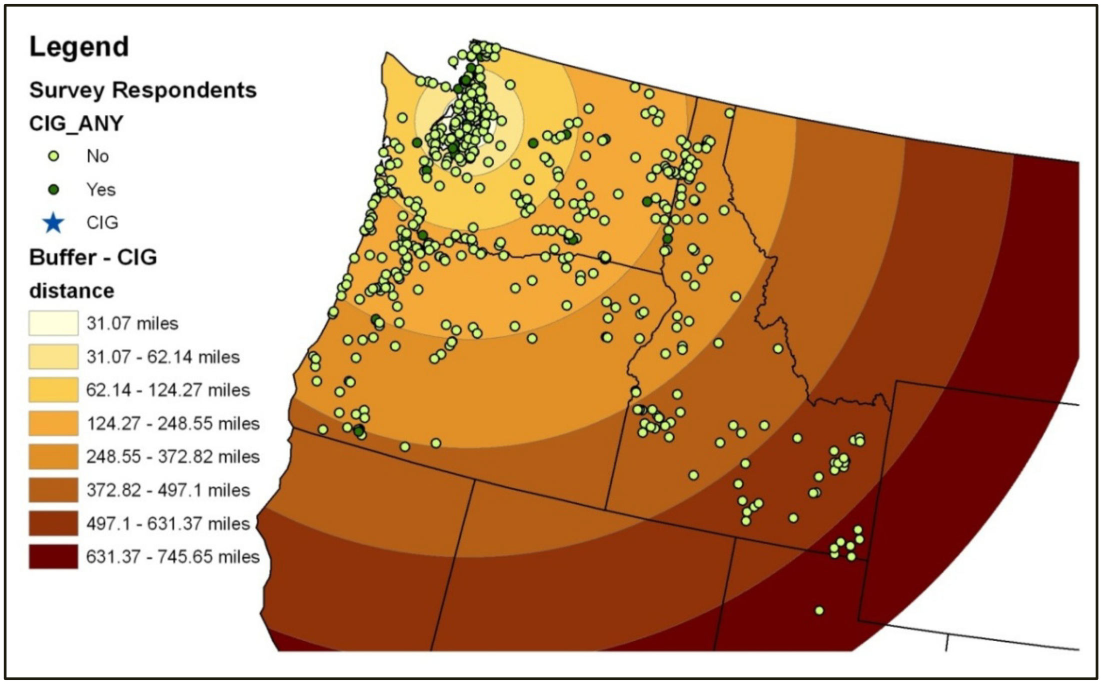


Figure 4.5 Geolocation of PNW CWS Survey Respondents and CIG.

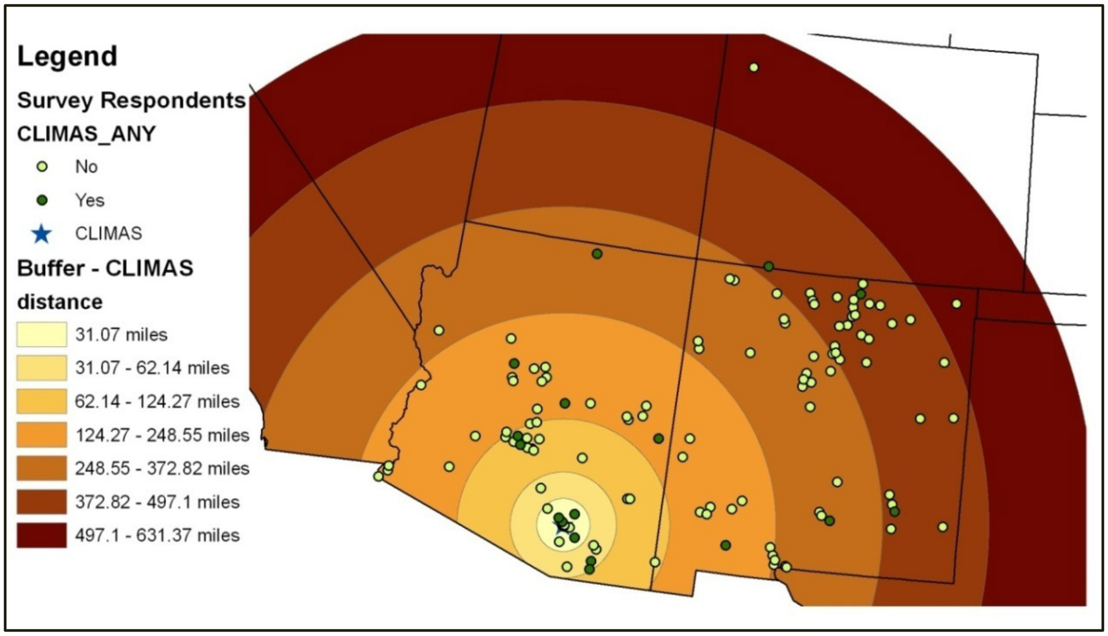


Figure 4.6 Geolocation of SW CWS Survey Respondents and CLIMAS.

Figures 4.5 and 4.6 use small light circles, indicating RISA information users, or dark circles, depicting non-RISA information users, to differentiate survey respondents that use or do not use RISA information. Concentric circles, shaded from light to dark, illustrate the distance in miles between the respondent's location and the location of the RISA. The lighter concentric circles represent closer Euclidean distance while darker circles represent progressively longer distance between respondents and the RISA.

The variable *Information sources*, used as an indicator of information-seeking behavior, was constructed from responses to two survey questions (SQ):

> *SQ-13* *Mark the boxes alongside the information sources you most often use to assist you with managing your system or for general information.*
>
> *SQ-14* *Mark the boxes alongside the information sources you most often use for weather or climate information (for example, precipitation, temperature, flooding, drought, reservoir levels, climate change, tree ring reconstructions, etc.).*

The measure was calculated as the percent of information sources selected by each respondent from a list of available Federal, state, private, and academic information sources. The information source was considered selected if it was marked as a general or a climate information source. The resultant *information sources* variable is continuous measure ranging from 0 to 100.

University collaboration, representing collaboration with any major research university in the home state of the respondent, was constructed from the question: “How much do you collaborate with the following organizations?” Respondents were presented with a list of universities in their home state and were asked to mark the amount of collaboration they engaged in with each university using a scale that ranged from “a lot,” “some,” “a little bit” to “none” or “never heard of.” The rank-ordered responses were collapsed into a dichotomous measure where a value of “1” meant collaborated “a lot,” “some,” or “a little bit,” and a value of “0” meant did not collaborate with the university. A CWS that collaborated with any state university among those listed within each respective state were coded as “1” for *university collaboration*. Systems that did not collaborate with any university were coded “0” for the measure.

Trigger (crisis) events /water supply threats

Questions about droughts and flooding were asked to illicit information about water managers’ experience with climatic variability. For the PNW surveys *drought* is a response to the yes/no question: “Severe drought has been a concern for my water system over the past 20 years.” A “yes” response was coded with a value =1 while a “no” response was coded with a value=0. *Drought* in the SW is the response to the question: “To what extent did the extreme drought period of 2001-2005 compromise your water system’s ability to deliver water?” where “1” meant “no impact at all,” “6” meant “very severe impact,” and “NA” meant “not applicable.” Responses to this question were collapsed to create a dichotomous variable for drought. “NA” or “1” responses were coded “0” while all others were coded “1”. In both the PNW and SW *flooding* is a response to the yes/no question: “Severe flooding has been a concern for my water system over the past 20 years.” Again, “yes” was coded as 1 and “no” as 0.

The *endangered species/instream flows* variable was derived from an ordered list question: “Select the three issues that are the most important to your system.” The 14 item list of potential concerns was ordered alphabetically and included: aging infrastructure, climate change, drinking water treatment, drought, endangered species/in-stream flows, flooding, groundwater depletion, growth, lack of financial resources, land use planning, regulation/compliance, source water quality, training/human capacity, and water rights/additional water supply. "Other" was also included as the 15th item along with space for a write-in response. CWSs that selected endangered species/instream flows as one of the three most important issues of concern for their system were coded "1". Systems that did not select endangered species/instream flows were coded "0".

Planning, technical capacity, and information use

Preliminary interview results indicated planning was an important factor affecting information use. For that reason questions were included to help gauge the level of planning for each system along with questions to assess the available technical capacity and the availability and use of information. To understand the state of planning for each CWS each respondent was asked about drought planning and comprehensive planning via two dichotomous yes/no questions:

> *SQ-15* *My system has a drought preparation and response plan.*
> *SQ-16* *My system has a comprehensive, long-term water management plan.*

Systems that had a drought preparation and response plan were coded "1"; systems that did not were coded "0". The same approach was used to code for presence or absence of a comprehensive, long-term management plan. Next, each respondent was asked about the use of real-time monitoring of source water quality and/or quantity to gauge the technical data gathering capacity available for system operation, management, and planning. This dichotomous yes/no question was coded "1" for the availability of real-time monitoring and "0" for no real-time monitoring. The use of models or other software in daily operation and management or for longer-term planning was also assessed as an indicator of technical capacity using two dichotomous questions coded "1" for model use and "0" for no model use. The two questions were:

> *SQ-17* *My system uses a water system model or other software to assist with daily water system operation and/or management.*

SQ-18 My system uses numerical or other models to assist with longer-term water system planning.

The availability and use of forecasts, tree rings or other climate proxies, and climate change information to help inform planning and management was also assessed through a series of questions. The three dichotomous yes/no questions were:

SQ-19 My system uses forecasts such as those for precipitation, temperature, flooding, drought, reservoir levels, or other similar information to inform water system operation and management.
SQ-20 My system uses tree ring data or other precipitation/drought event proxies to inform water system planning or management.
SQ-21 My system uses climate change scenarios or other climate change impacts information to inform longer-range water system planning or management.

The *use forecasts, use proxies,* and *use climate change* variables were created based on responses to each respective yes/no question. Respondents that indicated "yes" to using forecasts, proxies, or climate change information in water supply planning or management were coded "1"; systems that indicated "no" they did not use forecasts, proxies, or climate change information were coded "0" for each question as appropriate.

Public/customer pressure and concern for climate change

Lastly, the threat of public outcry or public pressure has been shown to influence information use. To operationalize this concept of a water manager's responsiveness to their public, the following yes/no question was asked of each respondent:

SQ-22 Our water customers/users ask us to consider climate change impacts in our longer-range water system planning or management.

The variable *customers ask* was coded as follows: respondents indicating "yes" customers asked them to consider climate change impacts in planning or management were coded "1"; respondents that indicated "no" were coded "0".

The last measure assessed respondent attitudes about the risk climate change posed for their water systems. This measure was used to create the variable *concern for cc impacts.*

Respondents who indicated climate change impacts on their water systems were a concern were coded “1”; respondents who marked “no” were coded “0”.

4.2.3 Exploratory and Summary Statistics

Descriptive statistics were performed to summarize data for all independent variables. Next, a series of statistical analyses were performed to: test the significance of relationships between groups, characterize and assess response rates and representativeness of the sample, and quantify potential relationships between the independent variables. Bivariate analyses were used to explore the association between the dichotomous dependent variable, *RISA use* or more specifically *CLIMAS* or *CIG use*, and continuous, ordinal, and categorical independent variables. For example, Independent samples t-test was calculated for each continuous or ordinal independent variable and the dependent variable *RISA use*. Chi-square tests were also performed to explore the association between categorical independent variables and *RISA use*. An alpha level of 0.05 was used for all statistical tests.

4.2.4 Logistic Regression

To better understand how independent variables predicted *RISA use*, a binary logistic regression model was developed. A logistic regression model was appropriate for this application because the dependent variable, *RISA Use*, was dichotomous (1=yes, 0=no) and the independent variables were a mix of discrete and continuous variables. Logistic regression is well suited for describing and testing hypotheses about relationships under these conditions (Peng *et al.* 2002). The equation for a logistic regression is as follows:

$$Logit(Y) = ln\left(\frac{\pi}{1-\pi}\right) = \alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_i X_i \qquad \text{EQ(1)}$$

Where, π is the probability of the event Y, α is the y-intercept, βs are regression coefficients, and Xs are a set of predictor variables (Harrell 2001). The value of the regression coefficient determines the direction of the relationship between X and the logit of Y. The logistic regression tests the null hypothesis that all βs equal 0. Rejecting the null hypothesis suggests that at least one β does not equal zero and that the logistic regression equation improves prediction of Y.

The goal of developing a logistic regression model is to find the best fitting, concise, and reasonable model that describes the relationship between a dependent (or response) variable and a set of independent (predictor or explanatory) variables (Hosmer & Lemeshow 2000). For this research, the goal is to develop a concise, reasonable model that helps explain RISA use. To find the best fitting, most concise, and reasonable model the first step is to determine which independent variables should be added to the model and which variables should be eliminated. Minimizing the number of variables generally produces a more numerically stable model and a model that is more easily generalizable. Adding too many variables to the model may lead to instability or overfitting the data.

Because the overall proportion of $y=1$ was small, understanding sample size and how that affects the development of the logistic regression model was an important consideration. Peduzzi *et al.* (1996) simulated a range of data sets that varied according to the ratio of the number of events of interest over the total number of variables. When compared against the original model, those models fit with events per variable ratios less than 10 were found to have biased regression coefficients and conservative Wald statistics among other issues. Generally speaking, to minimize potential model biases a minimum number of events per variable ratio of 10 is best (Peduzzi *et al.* 1996). However, it is possible to obtain a stable logistic regression model with fewer events per variable without having undue issues if the model remains stable. To calculate the recommended number of covariates the following equation was used:

$$N = 10\,k / p \qquad \text{EQ(2)}$$

where, p is the smallest of the proportions of negative or positive cases in the population, k is the number of covariates or independent variables, and N is the minimum number of cases to include. In this study $p=44/660$ and $N=660$ yielding $k=4$ as the number of variables to include in the logistic regression. However, as noted previously, more independent variables may be included if the model remains stable.

Now that the appropriate number of covariates has been determined, the next step is to further reduce the possible number of independent variables that might be included in the model by testing for association. If covariates are highly correlated, then including both in the model poses a multicollinearity problem. Therefore, only one of the highly correlated variables should be included in the model. Normally, a correlation value of 0.8 or higher indicates a strong correlation. However, even moderate correlations (i.e., values of 0.5) were carefully considered in the analysis.

The next step is to refine the number of independent variables for the logistic regression. There are two schools of thought when it comes to selecting variables for the logistic regression (Harrell 2001; Hosmer & Lemeshow 2000). The first is to include all intuitively relevant variables in the model regardless of their statistical significance. This approach controls for confounding and allows for inclusion of variables that might not be significant alone but that become significant when considered together. The problem with this approach is that it naturally leads to over fitting the data producing inflated coefficients and standard errors. The model is especially prone to overfitting if the overall proportion of $y=1$ is close to zero, which was the case with this data set. The second approach is to select variables based on results from bivariate analyses using a recommended cutoff significance level of $p=<0.25$ plus any variables that seem to be important but fail the significance test or that are derived from theory or experience. The second approach was used in this study using a significance cutoff of 0.25 augmented by: (1) the literature on barriers and drivers to information use; (2) preliminary results from the interview data; and, (3) elimination of co-variation concerns.

Because a few regional differences emerged from preliminary analysis of the interview data, three models were developed: one for overall RISA use and two others for CIG use and CLIMAS use to capture regional differences. The data for the CIG use model support a larger number of independent variables than the CLIMAS use model because the SW data set contains the lower number of $y=1$ for the dependent variable. Missing values were not included in the analysis; instead, casewise deletion was utilized as is standard practice in logistic regression analysis. Casewise deletion involves deleting any cases that have missing values on any variables of interest in the logistic regression model (Allison 2002). Evidence suggests casewise deletion may yield biased estimates in some cases particularly if the percent of missing values is high and if there is a relationship between the independent variables (Allison 2002; Harrell 2001). None of the independent variables used in the regression analysis had more than five percent missing. On the other hand, if the probability of missing data does not depend on any of the independent variables, then casewise deletion yields valid inferences and consistent estimates of coefficients and their standard errors in logistic regression (Vach 1994).

4.3 Limitations of the Study

There are several limitations to this study. First, the interview sample was non-random. Rather, the interviewees were chosen because of their status as RISA clients and their role in water policy, management and decision making. The results are informative but perhaps limited in terms of generalizability. Caution should be exercised when attempting to extend results to a broader population. While the interviewees do not reflect the population of water managers as a whole there was an attempt to select all possible federal, state, and county agency water managers and policy makers as well as all possible water utilities that were considered RISA clients. There was no attempt to interview individuals or representatives from both state level water resources and water quality agencies or to sample utilities to better represent the population. The primary focus was to interview all RISA water sector clients. Second, the literature review and research questions guided the development of the interview questions used in data collection. These questions may not have captured the full spectrum of information use employed by these interviewees. Further, because this study was focused on a single person within an organization, information use by that individual may not be representative of the suite of information used by the organization as a whole. However, individuals were selected for the interview because they had a higher likelihood of using RISA or other climate information given their status as RISA clients and involvement with the RISAs.

The survey sample was broader than the interview sample. However, response rates were low. Even with this low response rate an evaluation of representativeness (see Appendix 2) found respondents reflected the distribution of non-respondents in terms of population served (system size). This finding was encouraging because it indicated respondents shared an important characteristic of the survey population – a similar distribution of system size – improving the chance the data is somewhat representative of the broader population of water managers.

Chapter 5

Analysis of Information Use: Results and Discussion

Do water managers' use RISA-generated climate information or other climate information? If so, why do they use it and what sets RISA information users apart from non-users? Answering these questions is the aim of this chapter. Why are the answers important? First, they are important because research is an investment. Assessments like RISAs purport to provide useful information for decision makers. The Federal government through the National Oceanographic and Atmospheric Administration and others (e.g., state government research funding) finance these and other research efforts to derive that purported utility. What does society gain from the investment in research? Knowing more about who uses climate information and why they use it offers a partial answer. Second, the answers to these questions are important for creating the best information provision system possible. To do this, it is essential to know what works, why it works, and how to make it better.

Robust literature examines factors affecting information use in the Pacific Northwest (PNW; Callahan *et al.* 1999; Pulwarty & Redmond 1997; Rayner *et al.* 2005; Snover *et al.* 2003) and the Southwest (SW; Hartmann *et al.* 2001; Pagano *et al.* 2001), and other parts of the United States (Lemos 2008; O'Connor *et al.* 2005; Rice 2009; Yarnal *et al.* 2006). Addressing the first research question aims to contribute to the literature on barriers to and drivers of information use through the study of client and non-client RISA information users. Clients are water managers, classified as stakeholders by RISAs, who work directly with RISA scientists and outreach personnel. Clients were interviewed for this research. Non-clients are water managers who do not interact with RISAs as identified RISA stakeholders. Non-clients were surveyed for this research.

Data collected for this research enabled a deeper exploration of RISA information users (i.e., client and non-client) through comparisons across groups (e.g., utilities vs. state water managers, state vs. state, region vs. region, etc.). These comparisons permitted a more comprehensive examination of factors that affect information use as well as an exploration of regional and other contextual differences between groups that may influence information use.

The second thrust of this chapter is to better understand boundary management. The stakeholder-driven research approach employed by RISAs relies heavily on boundary work between RISA scientists and their clients to increase information use. Case studies indicated that boundary work, including communication and interaction, improves information use. Data collected for this research facilitated an empirical test of RISAs as boundary organizations by focusing on how interaction and other aspects of boundary work affect information use among RISA clients and non-clients. The last step was to empirically test the Iterativity Model (Lemos & Morehouse 2005) through examination of RISA information use.

5.1 Interview and Survey Response Rate and Representativeness

Thirty-eight water managers responded to a request for an interview from a total of 45 such requests, yielding an 84% response rate for the interviews. Rather than a representative sample of the population of water managers and policy makers in each RISA region, the interviewees were a targeted subset of RISA clients identified by Program Managers and Principle Investigators at CIG and CLIMAS. They were selected because, as clients, they interact with RISAs and are familiar with them. Because interviewees represented a non-random sample of RISA clients, conclusions from the interview data may not apply beyond this group or similar groups. However, data analysis indicated similarities between interview (clients) and survey respondents (non-client) information users suggesting that the interview analysis is more generalizeable to other RISAs (and perhaps other boundary organizations providing information for water managers) than non-random sampling might suggest.

While interviewees represented a purposefully non-random sample, the survey was administered to attempt to capture the diversity among water managers in the PNW and SW. The survey, administered to 2,645 water managers at Community Water Systems (CWSs) across the PNW and SW, resulted in 667 completed surveys for an overall response rate of 25%. Response rates from the PNW were higher than response rates from the SW. Response rates are summarized in Table 5.1.

Table 5.1 Interview and survey response (resp.) rates by region.

Data Collection Method	Southwest			Pacific Northwest		
	Resp.	Non-resp.	Resp. Rate (%)	Resp.	Non-resp.	Resp. Rate (%)
Interviews	22	4	84.6	16	3	84.2
Surveys	131	752	14.8	536	1226	30.4

A state-by-state analysis of survey respondents versus non-respondents was conducted to assess representativeness (see Appendix 2). The analysis was conducted using two variables: *population served*, an indicator of system size, and *primary water source*, an indicator of reliance on groundwater or surface water. Results from the Kolmogorov-Smirnov test indicated that the mean population served did not differ significantly between respondents and non-respondents. Results from the chi-square test for primary water source showed that proportionally more managers of surface water systems responded to the survey than managers of groundwater systems. Since primary water source was not a significant predictor of RISA use among non-clients and population served (i.e., system size) was an important predictor, representativeness in terms of mean system size was relatively more important than water source. The analysis of representativeness indicated that respondents were generally representative of non-respondents in terms of population served (i.e., an indicator of system size).

5.2 Rates of RISA Information Use

Most interviewees (84%) reported using RISAs as a source of climate information. All of the county interviewees, all of the federal interviewees, and more than 90% of the state and utility interviewees reported using RISAs. Table 5.2 summarizes RISA use by region.

Table 5.2 Summary of RISA use among clients interviewed by region.

	RISA Use		Total No. Interviewees	% RISA Use
	CIG	CLIMAS		
PNW Interviewees	15	0	16	93.8
SW Interviewees	0	17	22	77.3
		Totals	38	84.2

The fact that most of those interviewed for this study used RISAs was expected since the interviewees were purposefully, non-randomly selected among a subset of RISA clients. As clients, most of the interviewees are uniquely positioned to work alongside RISAs to develop usable climate information and, as such, are expected to exhibit high rates of information use.

In stakeholder-driven research, the boundary between information producers and information users is actively managed. This idea of a managed boundary increasing information use is consistent with effective knowledge-action systems (Cash *et al.* 2003) and with the iterativity model of science and policy co-production (Lemos & Morehouse 2005). For the former, as boundary organizations, RISAs effectively communicate, translate, and mediate information, increasing use (Cash *et al.* 2003). For the latter, RISAs' interdisciplinary approach and interaction with stakeholders improve the fit and usability of information, resulting in increased information use (Lemos & Morehouse 2005). The evidence of a high rate of RISA information use among clients illustrates that some stakeholders are benefiting from their relationship with RISAs. However, relatively little research has been devoted to understanding how the broader population of water managers (i.e., non-clients) benefits from RISAs. This relationship is explored in more detail in this chapter and in the subsequent chapter.

Less than a tenth (7.6%) of water managers surveyed reported using a RISA. This low number is made higher because it includes an overlap of seven RISA clients. The total number of RISA users, including this overlap, is summarized in Table 5.3.

Table 5.3 Summary of RISA use reported by respondents surveyed by region.

	RISA Use			No. Survey Responses	% RISA Use
	CIG	CLIMAS	Total		
PNW Surveys	32	0	32	536	6.0
SW Surveys	0	19	19	131	14.5
		Totals	51	667	7.6

While the total number of respondents who used RISAs (including the seven who were identified as clients) comprised only 51 CWSs, or 7.6% of the survey respondents, those CWSs serve a significant portion of the population in these regions. Those 7.6% of survey respondents who use RISAs provide water for 23.1% of the population served by CWSs (i.e., including both respondents and non-respondents) in the PNW and 41.6% in the SW. Hence, whereas the absolute number of systems using RISAs is small, they are important in terms of the overall population they served in their respective regions. However, when one removes the survey respondents who are RISA clients, the percent of the population served drops to 11.6% in the PNW and 9.7% in the SW. Table 5.4 reflects this adjustment, summarizing only non-client survey respondents using RISAs by region.

Table 5.4 Summary of RISA use reported by non-clients surveyed by region.

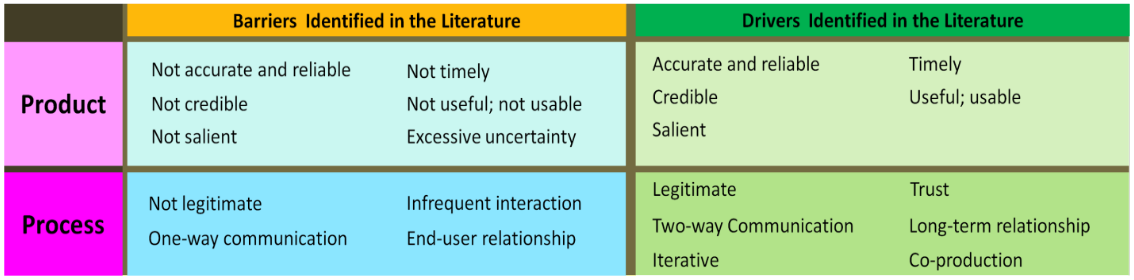
	Non-client RISA Use			No. Survey Responses	% Non-client RISA Use
	CIG	CLIMAS	Total		
PNW Surveys	28	0	28	532	5.3
SW Surveys	0	16	16	128	12.5
		Totals	44	660	6.7

Clearly, the finding that a mere 6.7% of non-clients use RISA information compared to 84.2% of RISA clients suggests that being a client increases information use. The difference in rates of information use points to the importance of boundary management (and, likely, other less obvious factors) and its' effect on information use. When the boundary is not actively managed, as in the case of the broader population of water managers, use rates drop precipitously.

5.3 Product and Process Factors that Moderate Information Use

Existing scholarship suggests a number of product and process (i.e., supply side) factors that moderate information use. This analysis began with the two components of information supply: (a) product factors (i.e., aspects about the information itself) and (b) process factors (i.e., aspects about the information production and dissemination) summarized in Table 5.5. On the left side of the table are the barriers, and on the right side are the drivers. The barriers and drivers are subdivided into two rows, with the top being product-related factors and the bottom being process-related factors.

Table 5.5 Factors that moderate information use identified in the literature



	Barriers Identified in the Literature		Drivers Identified in the Literature	
Product	Not accurate and reliable Not credible Not salient	Not timely Not useful; not usable Excessive uncertainty	Accurate and reliable Credible Salient	Timely Useful; usable
Process	Not legitimate One-way communication	Infrequent interaction End-user relationship	Legitimate Two-way Communication Iterative	Trust Long-term relationship Co-production

These product and process barriers were expected to act as impediments to information use among client and non-client water managers not using RISA information and perhaps to linger even when information was used. Lack of salience, perceived lack of information reliability, and uncertainty were among those factors hypothesized to impede information use. Lack of interaction and poor communication were also likely to affect information use, given that these indicate the presence or absence of boundary management efforts. Given the high rate of RISA client information use, I hypothesized that water managers who used RISA information did so in part because of boundary work. Other factors may also affect information use. For example, given previous research findings, the product and process factors most critical to effective knowledge-action systems salience, credibility, and legitimacy (Cash *et al.* 2003), expected fit between knowledge and use (Lemos & Morehouse 2005), and communication (Cash *et al.* 2003) or interaction (Lemos & Morehouse 2005) – will also likely play a role in driving information use among RISA client information users.

5.3.1 Results: Product and Process Barriers

As expected, uncertainty, lack of reliability, and lack of salience factored heavily in diminishing information use among water managers surveyed. Additionally, as hypothesized, there was a strong correlation between information use and interaction and, conversely, with non-use and infrequent interaction or one-way communication for both groups (e.g., clients and non-clients). Credibility, timeliness, and legitimacy were not selected as barriers to information use. In all, there was significant overlap among the product and process barriers to information use among clients and non-clients. Results for product barriers are summarized in Table 5.6, while process barriers are summarized in Table 5.7.

Table 5.6 Product barriers to information use among clients and non-clients.

Water Managers Not Using RISA Information			
Clients	**%**	**Non-Clients**	**%**
Not Salient	66	Not Salient	17
Information not Available	33	Information Not Available	49
		Too uncertain / Unreliable	20
Water Managers Using RISA Information			
Not Salient	28		
Too uncertain / Unreliable	34		

Table 5.7 Process barriers to information use among clients and non-clients.

Water Managers Not Using RISA Information			
Clients	**%**	**Non-Clients**	**Fisher's**
Infrequent Interaction^{SW}	100	Infrequent Interaction	p<.001
One-way Communication	50		
Water Managers Using RISA Information			
Infrequent Interaction^{SW+}	25		

SW Barrier more common among Southwest clients.

SW+ More common among Southwest clients than Pacific Northwest clients, 41% vs. 7% (p<0.05, Fisher's exact test).

5.3.2 Analysis: Product and Process Barriers

RISAs are considered to be a model for improved translation of science into policy because they address both product and process barriers to information use through an interactive research model that involves communication, translation, and mediation of information (Stern & Easterling 1999). Results from this study indicate that RISAs succeed at minimizing product and process barriers. Indeed, some barriers prominent in the literature, such as credibility and legitimacy of information (Cash *et al.* 2003; Pagano *et al.* 2001; Rice 2009), were not identified as critical barriers among water managers in this study. Instead, lack of salience and lack of information emerged as key barriers to information use among both RISA clients and non-clients.

The identification of lack of salience as a key barrier was expected, given reported findings regarding the importance of information relevance and fit in the literature (Cash *et al.* 2003; Lemos & Morehouse 2005; Pagano *et al.* 2001; Pulwarty & Redmond 1997; Stern & Easterling 1999). Lack of salience ran the gamut from aspects about the information itself to perceived lack of climate impacts to the lack of a policy mandate that might compel or support information use. For example, an interviewee in the PNW indicated that RISA information was too theoretical and academic to be relevant for his needs. Another reported not using RISA information because climate change impacts are not perceived to be relevant because the watersheds in their region are neither snow-dominant nor impacted by glacial recession. An interviewee in the SW said that without a mandate from the federal or state government to include climate change information, the information would not be relevant to the organization.

While data confirmed previous findings, data also revealed that lack of salience persisted as a barrier among RISA clients who use RISA information. This finding suggests that RISA clients may have greater tolerance for information that is partially relevant or that may become relevant in the future than non-client non-users who exhibit a more restrictive view of salience. This tolerance around salience may arise through relationships formed between clients and RISAs that fosters the development and use of information over time. It may also be a function of the characteristics of RISA clients compared to non-clients. For example, the latter may not have the luxury of investing time and resources to wait for information to become more relevant.

Both clients and non-clients identified lack of availability of information as a barrier to use. The fact that almost half of non-clients flagged this as a barrier could be taken as a positive sign, indicating a widespread desire for climate information among water mangers. However, from the data available, it is impossible to make a definitive determination about the strength or characteristics of any information needs that may exist in this group.

Accuracy, reliability, and uncertainty remain barriers to information use among non-client, non-users, confirming previous research that found water managers reluctant to use information they perceived to be inaccurate or unreliable (Callahan *et al.* 1999; Changnon & Kunkel 1999; Hartmann *et al.* 2002; Pulwarty & Redmond 1997; Rayner *et al.* 2005; Stern & Easterling 1999; Yarnal *et al.* 2006). Conversely, accuracy and reliability of information were not issues for RISA clients, suggesting that these concerns are effectively managed in the stakeholder relationships that develop between RISAs and water managers. For example, Lemos and Morehouse (2005) explained that interaction between scientists and stakeholders influences how RISA stakeholders understand the possibilities and limits of the science being produced. This increased understanding about the science and the scientific process itself garnered through interaction between scientists and information users may be important for managing product-related barriers to increase information use.

Interaction between RISAs and their clients also seems to shape clients' perception of uncertainty as a barrier. Uncertainty was an important hindrance to information use among non-clients and an enduring concern but not an impediment to information use for clients. The finding that uncertainty hinders information use among non-clients confirms earlier studies that found the same to be true among other groups of water managers (Callahan *et al.* 1999; Changnon & Kunkel 1999; O'Connor *et al.* 1999; Rayner *et al.*

2005; Rice 2009; Yarnal *et al.* 2006). More interesting was the effect that being a client had on curbing uncertainty paralysis. Here again, interaction appears to be critical to managing uncertainty, as clients used RISA information in spite of recognized high levels of uncertainty. Without the connection between RISA scientists and water managers, where uncertainty and concerns over accuracy and reliability are managed, these barriers increase and become obstacles to information use. This finding provides empirical evidence supporting Lemos and Rood's review of the impact of uncertainty and the use of science in decision-making (*in press*).

As the analysis moved from product to process barriers, infrequent interaction was found to be the dominant process barrier impeding information use among both client non-users and non-client non-users and limiting information use among clients. The data showed a clear and highly correlated relationship between interaction and information use, indicating that, without interaction, information use plummets. This finding confirms previous research which found that effective interaction between experts and decision makers is necessary to facilitate translation and mediation processes essential for increased information use (Cash *et al.* 2003). Cash *et al.* (2003) explained that interaction is a key component of successful knowledge-action systems. Similarly, Lemos and Morehouse (2005) argued that successful iterativity, a participatory research model developed through examination of CLIMAS, requires interaction with stakeholders to improve the usefulness and usability of information. In either case, without effective interaction and communication, information use declines.

One-way communication was another process barrier interviewees who used RISAs indentified. One-way communication goes hand-in-hand with infrequent interaction and reflects a pattern of limited engagement that, in turn, limits information use. One possible explanation is that dissemination of complex, uncertain, and potentially contentious information, such as information about potential climate change, without the opportunity for discussion decreases the likelihood that the information will be used.

5.3.3 Results: Product and Process Drivers

The most frequent product drivers of information use for clients were salience and usable information. Establishing a long-term relationship and ensuring two-way communication were also key predictors of client information use. For non-clients, RISA users' interaction and collaboration were key predictors of information use. Data limitations precluded measurement of two-way communication and of the length of continuous interaction between non-client RISA users and RISAs. Therefore, collaboration was used as an indicator of a sustained exchange. Interaction in general and two-way communication in particular seemed to be important precursors to information use.

Several drivers of information use identified in the literature did not appear to motivate information use here, including the (a) accuracy and reliability of the information, (b) perceived credibility, or (c) timeliness. Table 5.8 summarizes product- and process-related drivers of information use among RISA clients and the larger population of water managers (i.e., non-clients).

Table 5.8 Product and process drivers to information use among clients and non-clients.

	Water Managers Using RISA Information			
	Clients	**%**	**Non-clients**	**Fisher's**
Product Drivers	Salience	75	DNM	NA
	Usable Information	63	DNM	NA
Process Drivers	Long-term Relationship	72	Collaborative Interaction	p<.001
	Two-way Communication	63	Two-way Communication	NA

DNM = Did Not Measure

5.3.4 Analysis: Product and Process Drivers

Salience and usable information were the most important product drivers for RISA clients. For example, one interviewee from the SW worked with CLIMAS because "the water supply is so dependent on the rain that falls in the basin and in the area" (telephone interview, April 13, 2009). Having a source of climate information was essential to inform planning for water supply projects. Another interviewee described how climate information helped them monitor drought and inform local communities, while another spoke about their use of watershed-specific, reconstructed climate information to inform water supply planning. In the PNW, one interviewee described how RISA information informed planning for climate impacts on their water supply and informed their position at the negotiating table around discussions pertaining to water rights and instream flows. These results confirm the importance of salient (Cash *et al.* 2003; Lemos & Morehouse 2005; Pagano *et al.* 2001; Pulwarty & Redmond 1997; Stern & Easterling 1999; Wilbanks & Kates 1999) and usable (Changnon & Kunkel 1999; Lemos & Morehouse 2005; Pagano *et al.* 2001; Snover *et al.* 2003; Wilbanks & Kates 1999) information.

Though these results are consistent with previous research findings, they are nonetheless important, given the design of the RISA program to effectively and productively link information producers and users to improve information use. RISAs conscientiously and purposefully cultivate stakeholder relationships to help inform research agendas (McNie *et al.* 2005) and to ensure co-produced information is salient and useful for stakeholders (McNie 2008). Because most RISA clients are finding the information produced by RISAs to be salient and usable, the RISA model appears to be effective. The caveat is that success does not extend far beyond the RISA-client relationships.

Other established product-related drivers were not found to be important for information use in this study. For example, information accuracy and reliability, which Changnon *et al.* (1999) and Pagano *et al.* (2002) found to be important for information use, were not important drivers among RISA clients. One explanation for this absence may be that salience and usability are such dominant drivers that accuracy and reliability, while likely important, fell under the radar. A second explanation offered previously in the discussion of barriers to information use is that accuracy and reliability of information are managed in the interactions stakeholders have with RISA scientists. Knowing accuracy and unreliability were key barriers to information use among non-client non-RISA users but not among client non-RISA users and that accuracy and reliability are not dominant drivers of information use among RISA clients suggests that information accuracy and reliability inhibited information use among non-client non-users but did not drive information use for client RISA users. Therefore, accuracy and reliability of information was problematic for water managers (i.e., non-clients) who did not have the benefit of interaction with scientists when the information was being produced. On the other hand, RISA clients placed less emphasis on accuracy and reliability, either as a barrier or driver of information use, suggesting that the interaction with RISAs played a role. This makes sense, given the interactive research model employed by the RISAs that may also lead to increased understanding about science and the scientific process and, hence, a better understanding of the accuracy and reliability of RISA information. Once this happens, other aspects of the information like salience and usability become the predominant drivers of information use, as observed here.

The findings surrounding accuracy and reliability may have broader implications, given the attention paid to increasing forecast skill, model resolution, etc. These results suggest that the attention paid to increasing the accuracy and reliability of information only goes so far among the broader population of water managers, whereas scientist-stakeholder interactions seem to address concerns over the scientific product that otherwise impede information use among that larger population. Others have found that energy invested in making information more accurate and reliable may not actually result in higher rates of information use (O'Connor *et al.* 2005; Rayner *et al.* 2005). Given the findings reported here, it is perhaps not surprising O'Connor *et al.* (2005) and Rayner *et al.*(2005) found such a dismal return on product improvement.

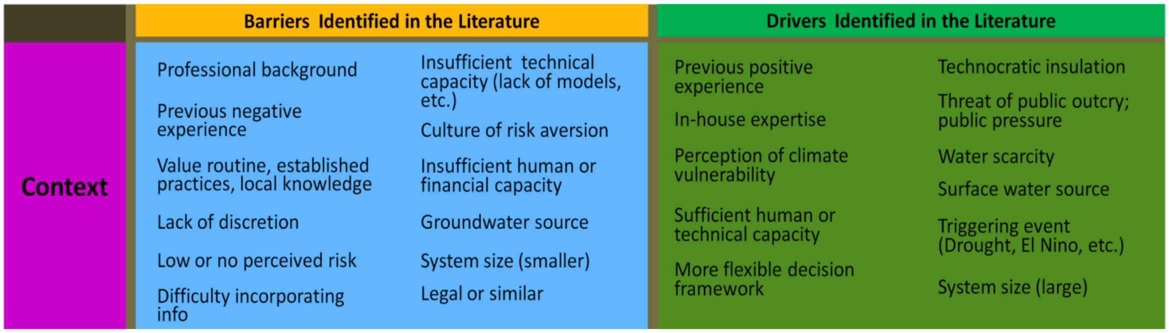
Two other characteristics of information credibility and timeliness found to be important for information use in previous studies (Cash *et al.* 2003; Pagano *et al.* 2002; Stern & Easterling 1999) were not found to be important drivers of information use in this research. Perceived credibility of information was mentioned by two RISA clients, but it was not a prominent factor driving information use. It is possible that perceived credibility plays a larger role earlier in the information production process than this research was able to test, given that the RISAs have been operating in each respective region for over a decade. For example, interaction with RISA scientists may increase credibility, but once that credibility is established, it is no longer a dominant driver but works in the background to benefit information use. Timeliness may be unimportant for a different reason. Some interviewees expressed awareness that working with information providers like a RISA differs from working with other potential information providers like consultants in terms of the amount of time it takes to get information. Often, it takes longer to get information through the RISA-stakeholder process than through a consultant. However, this factor was not a deterrent but seemed to come with the territory. RISA clients can tolerate longer lead times for some information, particularly if that information can only be produced by RISAs and if that information is tailored to the client's particular needs. There could also be a self-selection process at work that makes RISA clients different from other potential information users to whom timeliness is more critical. Overall, product-related factors seemed to play a more important role as barriers to information use than as drivers of information use. This pattern was consistent among RISA users and non-users alike.

Transitioning from product- to process-drivers one finds that two-way communication and establishment of a long-term relationship were important drivers of RISA use among clients, a finding that is consistent with previous research (Carbone & Dow 2005; Lemos & Morehouse 2005; Pagano *et al.* 2001; Rayner *et al.* 2005). For example, a number of interviewees from the PNW and SW described their relationship with the RISA as "long-term" or as "fairly long" or simply described the evolution of the relationship over time. Establishing a long-term relationship and facilitating two-way communication helps build trust between RISA scientists and water managers increasing the likelihood that information will be used. In their iterativity model, Lemos and Morehouse (2005) argued that interaction with stakeholders is an essential component for successful co-production of science and policy (together with interdisciplinarity and usability), which, in turn, leads to higher rates of information use, innovation, and societal impact. Given the tight association found between interaction and information use, results seem to confirm that interaction contributes to successful iterativity, which promotes information use among RISA clients. Furthermore, the high rates of information use among RISA clients and the tight coupling between interaction and information use indicated that RISAs may contribute to effective knowledge-action systems (Cash *et al.* 2003). Results also provided some evidence that interaction, even among non-clients, promoted RISA information use. As such, findings extended the importance of interaction to the broader population of water managers, confirming that higher rates of interaction yield increased information use among this larger population.

5.4 Context Factors that Moderate Information Use

RISAs and other interactive science/policy research programs that strive to produce information useful for decision makers have the most direct control over and opportunity to optimize the product and process factors (i.e., supply side) affecting information use. RISAs have little to no control over the context (i.e., demand side) within which information is used. This lack of control over the context poses a challenge for knowledge-action systems in their efforts to increase effectiveness by engaging across the boundary between science and policy. Context factors moderating information use are described in detail in the literature review and summarized in Table 5.9 for ease of reference.

Table 5.9 Context factors that moderate information use identified in the literature.



	Barriers Identified in the Literature		Drivers Identified in the Literature	
Context	Professional background Previous negative experience Value routine, established practices, local knowledge Lack of discretion Low or no perceived risk Difficulty incorporating info	Insufficient technical capacity (lack of models, etc.) Culture of risk aversion Insufficient human or financial capacity Groundwater source System size (smaller) Legal or similar	Previous positive experience In-house expertise Perception of climate vulnerability Sufficient human or technical capacity More flexible decision framework	Technocratic insulation Threat of public outcry; public pressure Water scarcity Surface water source Triggering event (Drought, El Nino, etc.) System size (large)

The following sections first examine context barriers for RISA clients and non-clients. Then, context drivers that promote information use for both groups are discussed. Finally, clients and non-clients are compared to see what broader insights might be gleaned.

5.4.1 Results: Context Barriers

RISA clients described a number of previously identified barriers and two new barriers to information use (See Table 5.10). The most important context barriers identified by clients not using RISA information (i.e., client non-users) were legal or other similar issues and the level of priority of climate information in their decision-making. Other important context barriers identified by client non-users included: (a) insufficient human or financial capacity, (b) a groundwater dominated water supply source, and less common, (c) lack of a policy mandate or support. A number of context barriers previously reported in the literature were not prominent among this group, including (a) an individual's professional background, (b) previous negative experience with information use, (c) lack of discretion, (d) low or no perceived risk, (e) difficulty incorporating information, (f) insufficient technical capacity, and, (g) a culture of risk aversion.

Many of the context barriers identified by client non-users persisted among clients who use RISA information (i.e., client users). For example, legal, regulatory, or similar issues and low or no perceived risk were also identified as barriers by client users. Additionally, other issues taking priority, insufficient human and financial capacity, and lack of policy mandate or support remained barriers to information use among clients using information. The most important barrier for non-client non-users was prioritizing other issues above climate concerns. Data limitations constrained further investigation into non-client context barriers. A summary of context barriers to information use among client users and non-users and non-client non-users is included in Table 5.10.

Table 5.10 Context barriers to information use among clients and non-clients.

Water Managers Not Using RISA Information			
Clients	**%**	**Non-Clients**	
Legal or Similar Issues[SW1]	83		
Other Issues Higher Priority	83	Other Issues Higher Priority	Note 1
Human or Financial Capacity[SW2]	67		
Groundwater Dominated Supply	67		
Water Managers Using RISA Information			
Legal or Similar Issues[SW]	41		
Other Issues Higher Priority	47		
Human or Financial Capacity[SW]	63		
Low or No Perceived Risk[SW3]	44		
Lack of Policy Mandate / Support	53		

[SW1] Driver more important among Southwest (SW) clients than Pacific Northwest (PNW) clients, 71% vs. 1%, p<.001, Fisher's exact test.

[SW2] Driver more important among SW clients than PNW clients, 88% vs. 33%, p<.01, Fisher's exact test.

[SW3] Driver more important among SW clients than PNW clients, 53% vs. 33%.

[Note1] Infrastructure and regulatory concerns had highest selection rate for top issues survey question.

5.4.2 Analysis: Context Barriers

A number of context barriers, some new and others already highlighted in the literature were identified in this research. The two most important barriers for client non-users were (a) legal issues or (b) other issues taking priority; these barriers were also important among client-users. The finding that legal or similar issues are a barrier to information use is consistent with the results reported by Pagano *et al.* (2001) and Rayner *et al.* (2005). Rayner *et al.* (2005) reported that allocation and adjudication of water rights, particularly in Southern California where scarcity is an issue, constrained forecast use. SW clients interviewed for this study reported similar constraints related to ongoing adjudication of water resources. The finding that prioritizing other issues over climate concerns impedes climate information use was new but expected. Interviewees stated that system maintenance needs, compliance with existing regulations, and provision of water for the current year had a higher priority than investing the time or effort to understand what might happen to the water supply several decades out. This finding suggests that attendance to climate issues competes with other, more pressing concerns for water managers. Both legal issues and prioritization have the potential to completely inhibit information use or simply moderate the amount and extent of information used. The latter finding (i.e., barriers persist to limit information use among client users) is consistent with results reported earlier in this chapter for product and process (i.e., supply side) barriers to information use. There, it was observed that product and process barriers to information use were moderated by interactions between clients and RISAs. Here again, the fact that these barriers persisted and limited but did not always forestall information use suggests that the RISA stakeholder relationship mitigated these context barriers as well. This finding is interesting in that it confirms that boundary work positively influences the demand side (i.e., context-related factors), not just the supply side (i.e., product and process factors).

Insufficient human or financial capacity was another barrier to RISA use found among both client users and client non-users. This finding is consistent with Pagano *et al.'s* (2001) finding that these organizational constraints limit forecast use. Like legal issues or other priorities, insufficient human or financial capacity has the potential to impede information use altogether if other barriers also intervene. SW clients in particular reported that insufficient budget and personnel limited information use. For example, several SW interviewees described plans to fund RISA research studies to provide basin-specific downscaled climate change information that were stymied by budgetary constraints. SW interviewees also pointed to the need to build internal staff expertise on climate issues to enhance their ability to interact and work with researchers on climate issues. Budgetary problems were not limited to the SW. An interviewee in the PNW said his agency was strapped for resources to do the things it needs to do now to get too "wrapped around the axle" on climate change information (telephone interview, June 8, 2009).

O'Connor *et al.* (2005) and Yarnal *et al.* (2006) reported that groundwater-dominant systems are less likely to use climate information, and indeed, this was the case for clients not using RISA information. However, this finding was not extended to the larger population of surveyed water managers. In fact, more groundwater than surface water systems used RISA climate information in this group. However, because more groundwater systems were represented in the sample, many more groundwater systems than surface water systems were not using RISA information. Still, the difference in water source and information use was not significant. The only significance for water source was found by considering both clients (i.e., those who completed a survey) and non-client survey respondents. Adding these surface water systems back into the mix resulted in the finding that groundwater dominant systems did not use RISA information significantly but only when water source was evaluated in a bivariate analysis. When controlling for water source in a multivariate analysis, water source did not predict information use. This result suggests water source played a role in information use for clients but not for the larger population of water managers. This may have had as much to do with the information product, which focuses on linking future climate change or past climatic variability with impacts on streamflow (i.e., impacts on surface water sources), than with perceived risk. Much less work has been focused on potential climate impacts for groundwater resources. For non-clients, factors other than water source better predicted RISA information use.

A low level of perceived risk from climatic variability and change was found to limit the use of information among clients using RISAs. Low perceived risk was previously identified as a barrier to forecast use by water managers in the PNW (Callahan *et al.* 1999), Arizona (Pagano *et al.* 2001), and Pennsylvania and South Carolina (O'Connor *et al.* 2005). Given Pagano *et al.*'s (2001) findings for Arizona water managers, it follows that SW clients were more likely to report low perceived risk limited information use. Though results confirmed previous findings, the situation is perplexing, given the apparent climate risks of a drought prone area.

The explanation for a dampening of the perception of climate vulnerability may lie in the high ratio of storage to precipitation coupled with conditioning around drought and scarcity. For example, one SW interviewee who reported a low level of risk to climate variability pointed to both available storage and past system reliability as reasons for his perceived low risk. Others seemed conditioned by routine drought and surprisingly dismissive of the risk posed by mega-droughts. For example, one interviewee pointed to the fact that rivers were flowing as a reason the climate impacts risks were low, even in a reported period of mega-drought. The interviewees' risk perceptions suggest two troubling conditions. First, reliance on infrastructure and past performance reliability masks a level of vulnerability that goes unacknowledged by some. Second, this finding suggests that the same sorts of drought response cycle that fluctuates between action and non-action paralleling rain and no rain, respectively, conditions climate information use as well. It is interesting that these perceptions and responses persisted among RISA clients. RISA-client relationships moderate product and process barriers and even some context barriers (e.g., legal issues and other issues higher priority). It is possible that some context barriers are more difficult to overcome, even when presented with information suggesting the potential for greater risk. Still, the fact that clients were using information in spite of low perceived risk suggests that boundary management may indeed be having a positive, even if limited, effect.

Another barrier that limited RISA information use among clients who used RISAs was a lack of a policy mandate or support. This represents a new, potentially encouraging context factor affecting climate information use for RISA clients. The identification of the lack of a policy mandate or support for information use suggests this subset of water managers (i.e., those who interact with RISAs) may want more institutionalized (i.e., regulatory) or organizational (i.e., agency policy) support for the integration of climate information in decision making. This finding was unexpected, given the general assumption that water managers resist additional regulations or the imposition of policy mandates. In fact, comments from interviewees suggested that the opposite may be true under some circumstances. These clients who are interested in using climate information to inform planning and decision making want a policy mandate or other policy framework to support inclusion of this information in decision making. This result likely reflects the learning that takes place as stakeholders interact with RISA scientists to better understand the potential uses of climate information. This learning process is one component of an interactive science/policy research model that leads to more information use (Lemos & Morehouse's 2005). Indeed, interaction and the learning that results from it may contribute to information use. If interaction builds a demand for information over time, as this finding suggests, then the lack of a mandate or policy may constrain information use, even when demand for it increases. Perhaps then, the implementation of an information use policy or an organizational shift in support for information use is required to further information use.

5.4.3 Results: Context Drivers

Analysis of interview and survey data found both new context drivers of information use and confirmed certain previously identified drivers of information use (see Tables 5.11-5.14). One newly identified driver of RISA information use is information-seeking behavior. Most RISA clients who sought information were more likely to use RISA information along with other information sources (see Table 5.11). For example, one interviewee from the PNW described how his agency struggled to understand what climate impacts were and how they might affect water resources in his state. He was able to use the RISA as a source of information to help inform decisions around managing water resources. Interviewees in the SW described a similar struggle to understand climate impacts specific to their watersheds. They too turned to the RISA to help provide much needed information. This driver of RISA information use held for both clients and non-clients. Non-clients who used RISA information used, on average, twice as many information sources as non-clients who did not use RISA information.

Table 5.11 Context drivers of information use among RISA clients.

Context Driver	%	Context Driver	%	*p*
Information Seeking	88	Human/Technical Capacity	63	NA
Commitment to Planning	88	Surface Water Source	63	NA
Collaboration	84	System Size (Population Served)	63	NA
Value Research	75	Reliable Water Supply^{SW}	NA	<.05
Endangered Species/Water Rights	63	Commitment from Upper Mgt.^{PNW}	NA	<.01
Climate Risks/Vulnerability	72			

^{SW} Driver prevalent among Southwest clients. Reported p-value is Fischer's exact test.
^{PNW} Driver prevalent among Pacific Northwest clients. Reported p-value is Fischer's exact test.

Another newly identified context driver is a strong commitment to planning. Water managers who exhibited a strong commitment to planning were more likely to use RISA climate information than were those who did not have an expressed commitment to planning (see Table 5.11). For example, one interviewee in the PNW described comprehensive water planning exercises in which water plans were developed and revised on 6-year cycles. Interviewees in the SW described planning efforts on 10-, 20-, and 50-year planning horizons. One individual in the SW described ongoing planning efforts spanning more than 100 years. For non-clients, indicators of planning were used for comparison. Having a drought response plan and using a model in long-term planning were significantly associated with RISA use among non-clients (see Table 5.13). However, a commitment to planning was not as important as information-seeking behavior and other factors (e.g., distance to RISA, etc.) that predicted RISA information use for this group when controlling for multiple variables (see Table 5.14).

RISA clients from organizations that fostered a culture of collaboration—either within the organization between individuals or separate departments or with external entities including other information providers, sector specific associations, or regulatory entities—were more likely to collaborate with RISAs and use climate information than those who did not. Unexpectedly, like information-seeking behavior, collaboration held as driver of RISA information use for both clients and non-clients. Non-client RISA information users were more likely to collaborate with universities or other organizations than those water managers who did not use RISA information.

Unsurprisingly, valuing research was also found to promote information use among RISA clients. Most of those interviewed who used RISA information valued research. One SW interviewee described looking to the RISAs to provide research and to feed that information to the utility so that the utility could develop policy based on good science. Other SW interviewees described how they wanted and valued research, particularly research critical to their specific water management needs that could help them better understand seasonal monsoon precipitation. In the PNW, one interviewee described how CIG helped him understand emerging issues and trends. Research specific to the needs of municipal water managers was also valued by PNW interviewees. PNW interviewees placed such a high value on research that they wanted to be involved in setting the RISA research agenda.

A more unexpected result was that water managers who needed to consider endangered species and water rights issues in their jobs used RISA information, especially considering that, as reported earlier in this chapter, legal issues were found to impede information use. Water rights and endangered species issues are normally lumped with other legal issues because of the association with various water laws and because of the Endangered Species Act, respectively. This finding suggests that not all legal or regulatory issues are barriers to information use, and in fact, some may actually drive information use. For example, water managers in the PNW spoke about issues surrounding the development of new water supplies, particularly those supplies that were already regulated for instream flows to protect endangered species. A number of water managers made it clear that climate change was not a pressing issue for the utility but could potentially impact firm yield far into the future.

Yet what became apparent in these conversations was that water managers are presently more concerned about the potential climate change impacts on instream flows. If air temperature increases, water temperatures also increase, resulting in conditions less suitable for the protection and propagation of endangered species. If higher temperatures result in the need to increase instream flows, then climate change might further constrain the amount of water available for withdrawal. With the pool of available water potentially decreasing and demand increasing with higher summer temperatures, there is a real risk for increased competition during peak summer months between within-stream and out-of-stream uses.

Interviewees in the SW also recognized the potential impact of climate change on endangered species. However, prior appropriation water rights were somewhat more of a concern, particularly in terms of shortages on the Colorado River. Climate change impacts may result in decreased water availability, putting states like Arizona, with lower priority rights than California, at a distinct disadvantage in shortage conditions. If climate variability or change results in shortage conditions on the Colorado River, large utilities that rely on its water will also likely suffer shortages. Even those not tied directly to the Colorado River expressed concern that having lower priority water rights might affect water availability. Like information-seeking behavior and collaboration, endangered species concerns held as a predictor of RISA use for non-clients (see Table 5.13). Importantly, endangered species concerns remained a predictor of RISA information use in the multivariate analysis (see Table 5.14).

Previously identified drivers of information use were also prominent among clients using RISA information. For example, most client users perceived some climatic vulnerability, confirming and extending previous research studies that indicated feeling at-risk from climate variability increased forecast use (Carbone & Dow 2005; O'Connor *et al.* 2005; Pagano *et al.* 2001). Here, interviewees expressed concern not just for vulnerabilities related to a variable climate but also risks related to potential climate change impacts. For example, a water manager in the SW expressed concern about the potential impact of climate change on snowpack. The concern centered on the fact that melting snowpack contributes to groundwater recharge in basins that provide baseflows to the river upon which the city relies during drought. This perceived vulnerability contributed to his interest in and use of climate information. Another interviewee acknowledged the natural climatic variability of the SW but expressed concern that climate change may lead to higher highs and lower lows, resulting in unknown but potentially negative impacts on his system. A desire to understand and quantify those potential impacts provided the impetus for RISA information use. Lastly, another SW interviewee expressed concern about accommodating additional growth, given the current demand/supply imbalance. Because climate change was expected to decrease the average annual inflow, he anticipated the demand/supply imbalance would likely increase.

The perceived risk from climate change was not just expressed by SW interviewees. For an interviewee in the PNW, glacial recession was the principle climate vulnerability because the water supply for his system was, in part, glacially dependent. Concern for climate change impacts was also significantly associated with RISA information use for non-clients in the bivariate analysis (see Table 5.13) but was not a significant predictor in the multivariate analysis (see Table 5.14). However, when both clients (i.e., those who completed the survey) and non-clients were included in the logistic regression, the result was a more pronounced concern for climate change impacts that remained significant in the multivariate analysis. The significance increased because every client who completed a survey expressed concern for climate change impacts compared to two thirds of non-client RISA information users.

A review of the survey data indicated that non-client non-RISA information users' rate of concern for climate change impacts was lower than non-client RISA information users, as expected. While the rate of concern about climate change among non-client non-users was lower, it was actually surprisingly high, given that 46% reported climate change impacts were a concern. While non-clients using RISA information are expected to have higher concern about climate impacts, it was interesting to find such a high percentage of non-clients express concern for climate change impacts overall. The concern for climate change was higher in the SW than in the PNW (χ^2 (1, N=635) =16.48, $p < .001$), but water managers used climate change impacts information at a higher rate in the PNW (χ^2 (1, N=640) =6.94, $p < .01$). Interestingly, not all of those using climate change impacts information (or forecasts) among the larger population of water managers (i.e., non-clients) reported using RISAs suggesting a higher demand for climate information than is being serviced by RISAs.

Another driver of information use identified in the literature was also found to be important in this study: human and technical capacity. While the presence of human and technical capacity as drivers of information use was expected, this finding extends previous research that applied to forecast information use (Lemos 2008) to include the use of climate change information. Having sufficient human and technical capacity enabled RISA clients to use climate information. For example, a number of interviewees described how models were used to help manage water resources and how climate change information could be integrated into those models. Thus, technical capacity enabled these water managers to more easily integrate climate information. Having sufficient technical staff was also described as a boon to the use of climate information. For non-clients, indicators of technical capacity, like using a model in daily operation and maintenance or for long-term planning, were associated with information use. However, these indications of technical capacity lost significance when tested in a multivariate analysis.

Similar to Yarnal *et al.* (2006), here too, results indicated surface water dominant systems were more likely to use RISA information. Yarnal *et al.* (2006) surveyed over 600 water managers in Pennsylvania and South Carolina and found that large surface water systems were more likely to use forecast information. Here, RISA clients who managed large surface water systems were more apt to use RISA information. However, water source was not a significant predictor of information use among non-clients. This suggests that while water source was an important consideration, it was not among the most critical factors predicting climate information use among the broader population of water managers.

Two regionally dominant drivers were also found to be important. One of these, a commitment to a reliable water supply, emerged as an important driver of information use among SW clients but not PNW clients. More interviewees in the SW than in the PNW identified commitment to a reliable water supply as an important driver of information use (see Table 5.11). The regional importance of maintaining a reliable water supply among SW water managers persisted among non-clients (see Table 5.13). However, this commitment to a reliable water supply did not hold as a significant predictor of RISA information use in a multivariate analysis. The idea of water supply reliability as an important motivator is consistent with Rayner *et al.* (2005), who found that water managers at the Metropolitan Water District of Southern California, the Northwest Power Planning Council, and the Interstate Commission on the Potomac River Basin shared a common goal: providing a safe, reliable water supply. However, Rayner *et al.* (2005) found that this commitment to a reliable water supply inhibited the use of climate information because it fostered a conservative, risk-adverse approach. The difference in findings may be attributable to differences in the characteristics of the water managers interviewed. For example, the overall conservatism detailed in Rayner *et al.* (2005) may be a function of the large, bureaucratic organizations from which interviewees were drawn, compared to the variety of larger but generally less fragmented organizations from which interviewees were drawn for this study.

A second regionally important driver of information use was support from upper management. This driver was found to be predominant among interviewees in the PNW (see Table 5.11), which is consistent with an earlier reported finding that lack of a policy mandate or support impeded information use. Therefore, it makes sense that having support from upper management would drive information use. For those clients interested in using climate information to inform planning and decision making, having institutional or organizational support facilitated the use of climate information.

A number of drivers previously identified in the literature were not dominant among RISA clients. These drivers included (a) the threat of public outcry or public pressure, (b) triggering events, (c) previous positive experience, and (d) professional background. Although these drivers were mentioned by some interviewees, they were not reported by a significant proportion of interviewees to suggest they were as important to information use as other drivers. For example, two interviewees reported their professional background helped inform their use of climate information. The threat of public outcry or public pressure was not mentioned as a driver. However, one interviewee reported that public support fostered climate information use, while another reported that, when framed correctly, the public supported prudent use of climate information.

5.4.3.1 Bivariate Analysis of Non-client RISA Use

Analysis of the survey data provided an opportunity to examine context drivers among a broader population of water managers in the SW and PNW. Many of those results have already been discussed in the context of the interview data. Those that have yet to be discussed are summarized here to provide a full accounting of the analysis. For example, an independent samples t-test was calculated for each continuous or ordinal independent variable and the dependent variable RISA use. The t-test was used to explore the relationship between RISA use and (a) distance to RISA; (b) population served, a proxy for system size; and (c) the number of information sources, as a proxy for information-seeking behavior. Test results indicated a statistically significant association between RISA use and the independent variables when testing each variable individually.

Consistent with Yarnal *et al.* (2005), larger systems, measured in terms of population served and total yearly budget, were more likely to use RISAs. Additionally, proximity was found to be important: systems that were located physically closer to the RISAs were more likely to use RISA information. The same was true among RISA clients from local utilities. These clients averaged 76 miles closer to the RISA on average than non-client RISA users who were, on average, 124.9 miles away from the RISA. Both RISA clients and non-client RISA users were closer than non-client non-RISA users who were, on average, 209 miles away from RISAs. However, when interviewees were considered in a group (i.e., local utilities, regional and state water managers) and compared to non-client non-RISA users (i.e., local water managers), there was no statistical difference in the average distance from RISAs. Also, distance seemed to be significantly associated with RISA collaboration and with overall RISA use among non-client RISA users. Results of these bivariate analyses are summarized in Table 5.12, wherein "M" indicates means and "SD" designates standard deviations.

Table 5.12 Independent Samples t-test results for RISA use among non-clients.

		No RISA Use (n=616)	RISA Use (n=44)	*t*-value	*p*-value
Distance (miles)	M (SD)	208.8 (151.0)	124.9 (116.7)	4.51	< 0.001
lnPopulation	M (SD)	6.2 (1.9)	8.4 (2.5)	-5.62	< 0.001
Information Sources (%)	M (SD)	24.0 (18.0)	50.7 (29.6)	-5.92	< 0.001
Total Yearly Budget	M (SD)	2.2 (1.1)	3.4 (1.2)	-6.03	< 0.001

Bivariate analyses between categorical independent variables and non-client RISA use are summarized in Table 5.13.

Table 5.13 Chi-square results of non-client RISA use.

	RISA Use		
Variable	χ^2	d.f.	p-value
Primary Water Source	4.92	2	0.09
Aging Infrastructure a Concern	2.41	1	0.12
Endangered Species a Concern	13.97	1	<0.01[a]
Staying up-to-date with the latest Information	4.62	1	0.04[a]
Experience Drought	17.71	1	<0.001
Experience Flooding	5.09	1	0.024
Have a Drought Preparation and Response Plan	18.83	2	<0.001
Use Forecasts	20.58	1	<0.001
Use Tree Ring Reconstructions/Climate Proxies	15.59	1	<0.01[a]
Concern for Climate Change Impacts	8.32	1	<0.01
Customers Ask to Consider Climate Change	24.48	1	<0.001
Use Climate Change Information	50.14	1	<0.001
Use Model in Daily Operation & Maintenance	11.31	1	<0.01
Use Model for Long-term Planning	18.89	1	<0.001
Collaborate with University	49.94	1	<0.001

[a] Fisher's exact test.

Some of the results summarized in Table 5.13 have already been discussed, including (a) water source, (b) endangered species, (c) drought planning, (d) concern for climate change, and (e) collaboration. However, not all of the results have been discussed, and some, particularly those that confirm or call into question previous research findings or those that indicate new information, warrant a more detailed explanation. For example, consistent with other research findings, this study also found that water managers (i.e., non-clients) who experienced drought were more likely to use climate information, whether in the form of forecasts (Hartmann *et al.* 2002; O'Connor *et al.* 2005; Pagano *et al.* 2001) or tree ring reconstructions (Rice 2009).

One of the new findings to emerge through this analysis is the association between use of climate information and RISA use. For example, respondents who use forecasts, climate change information, or tree ring reconstructions were also more likely to use RISAs. While the use of climate information (i.e., forecasts, climate change, tree ring reconstructions or proxies) was associated with RISA use, the data indicated that water managers not using RISAs still used forecasts and climate change information, but they obtained the information from other sources. For example, 23.6% of non-client non-RISA users used forecasts, compared to 54.5% of RISA users, and 6.9% used climate change impacts information, compared to 38.6% of RISA users. Lastly, another new finding to emerge is that water managers whose customers asked them to use climate information were more likely to use RISAs.

5.4.3.2 Multivariate Analysis of Non-client RISA Use

The bivariate analysis revealed statistical associations between RISA use and several independent variables. Unfortunately, the analysis did not enable a distinction between the relative importance of the independent variables as drivers of RISA use. To understand the relative importance of the various predictors of RISA information use, a multivariate analysis was performed. Because RISA use is a binary response variable, a binary logistic regression was appropriate (for a detailed, step-by-step description of variable selection and model development, see Appendix 3, and for a thorough discussion of logistic regression, see Chapter 3). A limitation of the binary logistic regression is that it assumes a linear relationship between the predictor and transformed response (Hosmer & Lemeshow 2001). Validation of the model required using the developed model(s) to predict RISA use using another independent data set. Model validation is left for future work.

Table 5.14 presents the results of the regression model for overall *RISA use* and the two regional regression models for *CIG use* and *CLIMAS use*, respectively. All models control for system size, using the natural log of population served (*lnPopulation*) as a proxy, and *primary water source*. This facilitates understanding the relative importance of the independent variables (a) distance (accessibility of expertise), (b) information seeking, (c) collaboration, (d) concern for endangered species/instream flows, (e) experience of drought, and (f) use of climate proxies at predicting *RISA use* controlling for system size and water source. Primary water source was included as a control variable because source of supply has been previously identified as an important predictor of climate information use (O'Connor *et al.* 2005; Yarnal *et al.* 2006).

Table 5.14 Final Regression Models with Log Odds, Standard Errors, and Confidence Intervals

Overall RISA use regressed on natural log population served, collaboration, information sources, distance, use of proxies, endangered species/instream flows, and drought

	Final Model RISA Use				
	Coeff.	Std. Error	p-value	Exp(β)	95% C.I.
lnPopulation	0.219	0.098	0.025	1.25	(1.03, 1.51)
Collaboration	1.718	0.456	0.000	5.57	(2.28, 13.6)
Information Seeking	0.044	0.009	0.000	1.05	(1.03, 1.06)
Distance (miles)	-0.009	0.002	0.000	0.99	(0.98, 0.99)
ES / IS Flows	1.730	0.846	0.041	5.64	(1.01, 29.6)
Experience Drought	1.729	0.456	0.000	5.64	(2.31, 13.8)
Constant	-5.991				

Pacific Northwest: CIG use regressed on natural log population served, distance, collaboration, information sources, endangered species/instream flows, and drought

	Final Model CIG Use				
	Coeff.	Std. Error	p-value	Exp(β)	95% C.I.
Distance (miles)	-0.013	0.003	0.000	0.99	(0.98, 0.99)
Collaboration	2.272	0.615	0.000	9.70	(2.91, 32.4)
Information Seeking	0.060	0.012	0.000	1.06	(1.04, 1.09)
Endg. Spec/ IS Flows	1.937	0.920	0.035	6.94	(1.14, 42.1)
Experience Drought	1.429	0.650	0.028	4.17	(1.17, 14.9)
Constant	-5.215				

Southwest: CLIMAS use regressed on collaboration, use of proxies, and information sources

	Final Model CLIMAS Use				
	Coeff.	Std. Error	p-value	Exp(β)	95% C.I.
Distance (miles)	-0.006	0.002	0.017	0.99	(0.98, 0.99)
Use Proxies	1.68	0.937	0.050	5.36	(0.85, 33.6)
Information Seeking	0.022	0.009	0.019	1.02	(1.01, 1.04)
Constant	-1.563				

* Significant at 0.05, two-tailed test.
** Significant at 0.01, two-tailed test.
*** Significant at 0.001, two-tailed test.

5.4.4 Analysis: Context Drivers

The examination of context drivers revealed that sufficient human and technical capacity were a moderate drivers of information use among RISA clients, and support from upper management was important but only in the PNW. Results indicated more important drivers of information use among RISA clients were factors such as (a) information seeking, (b) commitment to planning, (c) culture of collaboration, and (d) valuing research. Taken together, these factors paint a picture of an evolution of the water management culture. Contrary to the more traditional view of water managers who are risk averse (Callahan *et al.* 1999; Pagano *et al.* 2001) and who value routine, established practices, and local knowledge (Callahan *et al.* 1999; Pagano *et al.* 2001; Pulwarty & Redmond 1997; Rayner *et al.* 2005), interviewees using RISA information are more likely to (a) embrace new knowledge, (b) search outside their organization for information, and (c) plan to better manage risk. In some ways, RISAs enable that evolution by providing a new, non-traditional information source and by fostering the stakeholder relationship. That is not to say RISAs sparked the change; rather, water managers who engaged with RISAs and used climate information were likely already moving in novel directions and, in so doing, were better able to take advantage of RISA information, leading to a convergence of supply and burgeoning demand for or interest in climate information.

Results from the regression of survey data cautiously extend this finding to the larger population of water mangers in the PNW and SW. For example, collaboration and information seeking predicted RISA use among water managers surveyed. Information-seeking behavior may also indicate that RISA information users (clients and non-clients) leveraged multiple information sources to help manage risk. Given that climate risks are uncertain, this finding may reinforce what others have suggested: in the face of uncertainty, information users bundle ensembles of information to help bound uncertainty.

Another important driver of information use among RISA clients and non-client RISA users was endangered species/instream flows. The significant positive association between concern for endangered species/instream flows and overall RISA use appear counterintuitive at first. However, given the importance of salmon recovery in the PNW and the fact that numerous aquatic species are sustained by water availability in the arid SW (Graham 2007), the results make sense. For the PNW, endangered species/instream flows remained an important predictor in the final *CIG Use* model (see Table 5.14). This reflects the context of managing water resources in the PNW where salmon are a listed species and where instream flow designations coupled with climate variability and change may limit available water supply now or in the future. CIG researchers working within an interdisciplinary, interactive research model helped to quantify potential climate impacts across multiple sectors and policy areas, including fisheries, hydropower, and municipal water supply linked through the core element of water resource availability. This integration of climate impacts was a key benefit to RISA's integrative assessment approach and ultimately served an important need for the region.

While water managers in the SW were keenly aware of and concerned about climate impacts on endangered species, endangered species/instream flows were not as important a predictor of *CLIMAS Use*. Instead, in the drought-prone SW, a variable that indicated a water manager's use of tree rings or other climate proxies best predicted CLIMAS use. This result was not entirely unexpected, given the fact that CLIMAS researchers have a lengthy record of reconstructing the history of past climatic variability using tree ring data. Over the last decade, CLIMAS scientists have spent a considerable amount of time and energy educating water managers about the benefits derived from tree ring data (telephone interview, November 4, 2008; telephone interview, November 7, 2008). As the supply of tree ring information increased on the one side, demand for the information also increased, fueled by the potential for increased scarcity given regional population growth and an expectation that longer, more severe droughts than had been experienced in the past were possible. Water managers wanted to look beyond the 100-year historic record to better understand these risks, and tree ring reconstructions provided this much needed longer view, ultimately confirming the existence of more severe droughts over past centuries.

The focus on tree rings and climate variability suggests water managers in the SW were not concerned about climate change. On the contrary, SW water managers expressed interest in having a greater understanding of potential climate change impacts, but that interest remained largely unexpressed because global climate models did not capture orographic or monsoon precipitation patterns, which are important in the SW. This pattern was somewhat repeated among the larger population of water managers surveyed. Findings showed that two thirds of water managers in the SW were concerned about climate change compared to two fifths of the water managers in the PNW. While the concern was greater among SW water managers, more water managers in the PNW used climate change information than in the SW. For SW RISA clients, the lack of region- or basin-specific climate change impacts information from climate models has led to creative use of proxy information to help plan for possible futures. The longer record of historic climatic variability obtained through the use of tree ring reconstructions provides some of this much needed information. While CIG provides climate change impacts information to water managers needing to quantify impacts on endangered species/instream flows in the PNW, scientists at CLIMAS provide tree ring reconstructions for water mangers in the SW. This suggests that each RISA serves an important niche in the region by helping water managers cope with climate variability and change. Importantly, these context drivers applied to both clients and non-clients across the two study areas.

Studies have shown that triggering events such as droughts increase information use (Callahan *et al.* 1999; Hartmann *et al.* 2002; O'Connor *et al.* 2005; Pagano *et al.* 2001; Rice *et al.* 2009; Schwarz & Dillard 1990; Yarnal *et al.* 2006). Results from the regression for overall RISA use confirmed that drought is an important predictor of RISA use. One might expect drought to be a more important predictor of CLIMAS use in the arid SW than of CIG use in the PNW. Surprisingly, results indicated just the opposite: drought was a better predictor of CIG use. A closer look at water and storage availability in the PNW versus in the SW helps to explain this result. First, most of the rainfall in the PNW falls west of the Cascades, leaving most of eastern Washington and Oregon and much of Idaho much drier. Second, water storage in the PNW is often inadequate during low snowfall years, as snow provides a fifth reservoir necessary to meet yearly demands because reservoir capacity alone is insufficient to bridge from wet to dry years (Gleick 1990; Hurd *et al.* 1999). The climate variability coupled with low storage relative to yearly demand makes it easier to understand why drought might be a motivator for RISA use in the PNW, particularly if climate change may affect the timing and amount of water available in the future.

On the other hand, the SW has greater experience with recurrent drought. Furthermore, while the SW receives much less rain, available storage is much greater (Gleick 1990;

Hurd *et al.* 1999), which helps water managers bridge dry years. The risk for water managers in the SW occurs when natural climatic variability or climate change precipitates much longer and more severe droughts than normally experienced in the region. The interest in understanding drought through the use of tree ring reconstructions helps explain why use of climate proxies is a better predictor of RISA use in the SW than drought. The cautionary note for the SW arises when one considers the earlier finding that SW stakeholders are more likely to perceive a low level of risk from climate variability and change and that low level of perceived risk may act to limit information use. It may be that reliance on infrastructure and past performance masks a level of vulnerability that goes unacknowledged by some. However, the use of climate proxies indicated that some SW RISA clients were aware of the risks posed by climate variability and climate change and were seeking proxies to inform decision making rather than purely relying on past performance to get them through water scarcity. Lastly, the surprising finding of a high level of concern about climate change impacts among non-client RISA users in the SW (and PNW) indicated an awareness of and concern for climate vulnerability among the broader population of water managers.

Interestingly, results from the analysis of survey data indicate access to relevant expertise is important; in fact, the closer the better. Distance to RISA was a significant predictor of overall RISA use among clients who were also managers of local water utilities and non-clients. This proximity finding was somewhat expected, given the importance of collaboration and communication in driving information use and given the RISA's interactive research approach. A possible explanation for the importance of distance is that a water manager's physical proximity to a RISA increases the ease and convenience of forming and continuing working relationships with RISA scientists. This was particularly true among water managers from large utilities who were RISA clients and for non-client RISA users who were, on average, significantly closer than non-client non RISA users.

However, when all RISA clients (i.e., local, regional, and state water managers) were compared to non-client non RISA users (i.e., local water managers), distance was not significant. When all clients were considered, including some from adjacent states who were among the farthest from the RISAs to use RISA information, it was evident that, in fact, being a RISA client—broadly defined—reduced the importance of proximity for RISA use. This finding might suggest that once water managers become clients and a relationship is established, alternative modes of communication become possible, lessening the importance of physical proximity. This seemed to be especially true for state-level water managers over regional or local water managers. For non-clients, distance seemed to be an important parameter, but it was more important for users who indicated they collaborated with RISAs than for users who reported they used RISAs for informational purposes only.

Other factors may also drive the association between distance and RISA use. For example, physical proximity may simply increase the likelihood of familiarity with the RISA, which may lead to increased information use. However, interaction was also an important predictor of RISA use, suggesting that familiarity may not be a sufficient explanation. Alternatively, RISA budgets may also influence distance. CLIMAS' work in New Mexico was limited because the cost of travel was high, making closer work more attractive when budgets are constrained (personal interview, October, 28, 2008). This suggests that capacity issues for the information supplier and interaction may contribute to the importance of proximity in predicting information use. If physical proximity is an important driver of information use, as these findings suggest, these findings lend support to those who argue there should be more RISAs or climate centers to better meet local information needs. Results may also support additional investment in virtual communication to help maintain stakeholder networks, once they are established. These same results are also a cautionary tale: regional organizations are limited in their ability to effectively serve the entire region if, as seems to be the case, physical proximity and interaction with information users are necessary preconditions to establishing stakeholder networks and to increasing information use (particularly at local levels).

5.5 Discussion: Conditions that Promote/Impede RISA Information Use

The next step was to further examine the significant product, process, and context barriers and drivers that emerged in this research to condition RISA information use. Up to this point, the presence and significance of each barrier or driver had been established to postulate a rationale for its significance in this study and to note how it relates to previous work and to information use here in particular. The next step was to examine the barriers and drivers together, first from the perspective of non-clients and then from the perspective of clients where the barriers and drivers were conditioned through the RISA. To do this, it was helpful to think about the models of the science production process. Interactive research models, including the iterativity model, look to discover stakeholder information needs through interactions to produce useful and, ultimately, usable science. In that way, interactive research models aim to better match the supply and demand for information by managing the boundary between producers and users of science. This research model can be usefully contrasted with the loading dock or linear model of science production, which assumes potential information users will make use of the information without the interaction component. These contrasting models are illustrated in Figure 5.1.

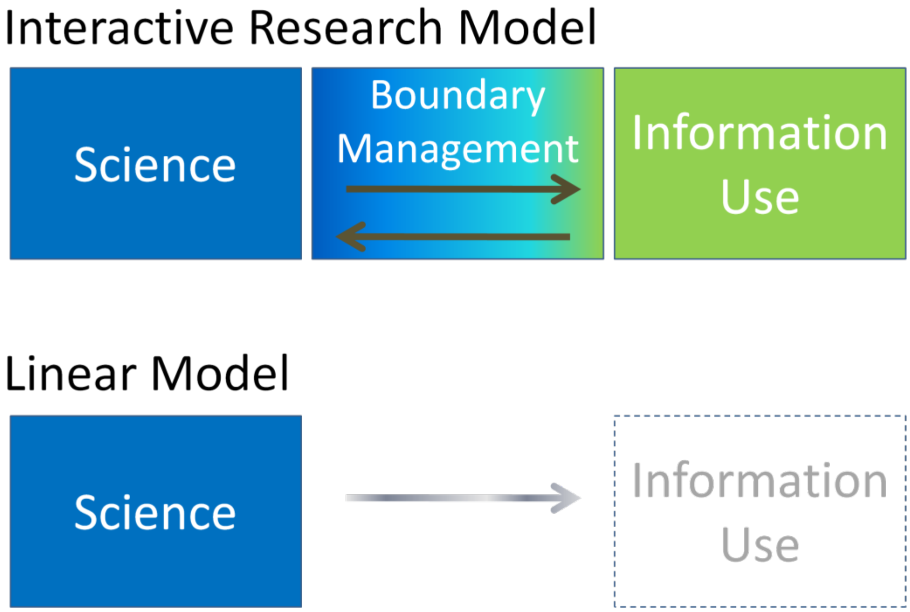


Figure 5.1 Science-to-policy models.

5.5.1 Moderating Barriers to Information Use

Case study research has shown that the interactive research approach produces more usable information because scientists are better able to meet the needs of potential users through boundary work (i.e., communication, translation, mediation). To test the effect of boundary work in practice and examine how RISAs mitigate barriers to information use, differences between clients' and non-clients' use of information had to be examined. A summary of barriers to information use is included in Table 5.15 for ease of reference. In the next section, similarities and differences between information drivers that emerged for clients and non-clients are explored.

Table 5.15 Summary of barriers to information use among clients and non-clients.

	Water Managers Not Using RISA Information	
	Clients	**Non-clients**
Product Barriers	Not Salient*	Not Salient
	Information not Available	Information Not Available
		Too uncertain / Unreliable*
Process Barriers	Infrequent Interaction*	Infrequent Interaction
	One-way Communication	
Context Barriers	Legal or Similar Issues*^{SW}	
	Other Issues Higher Priority*	Other Issues Higher Priority
	Human or Financial Capacity*^{SW}	
	Groundwater Dominant Supply	
	Water Managers Using RISA Information	
	Low or No Perceived Risk^{SW}	
	No Policy Mandate or Support	

* Barrier persists among clients using RISA information.
^{SW} Driver prevalent among Southwest clients.

As discussed earlier in this chapter, some barriers acted as obstacles to information use independent of group membership (i.e., RISA clients and non-clients) while others were moderated such that they limited but did not impede information use, depending on group membership. An obvious example of the former on the supply side was the absence of desired information. Without perceived desirable information available, there was a severe curtailment of information use independent of group membership, although somehow clients did use tree ring information as a proxy for information about future climate change because downscaled climate change information was not available. Another barrier that impeded information use for both clients and non-clients was infrequent interaction. Without interaction, the boundary work that helps moderate potential barriers lagged, leading to non-use for non-clients and diminished use for clients.

The discussion of barriers that impeded use was less revealing. Rather, what was more interesting was examining barriers that persisted among clients as a means to examine the effect of boundary work. Uncertainty in information is a good first example. An enormous amount of attention has been placed on scientific uncertainty, particularly as it relates to global climate modeling of future potential climate change. Given the challenges in predicting population and economic growth and national and international policy responses to reduce greenhouse gas emissions, on the one hand, and the challenges of predicting temperature and precipitation effects, on the other, it is no wonder potential information users were wary of the uncertainty embedded in global climate models. The wariness is understandable, given the broad range of future possible conditions and the reality that policy makers are faced with committing real and often scarce resources to mitigate an uncertain range of outcomes. Uncertainty has also delayed actions. The difficulty in making decisions in the context has been used to justify large amounts of investment in science to reduce uncertainty. But along with that investment in the science was an investment in dialogue about communicating uncertainty and the recognition that some uncertainty is irreducible. This shift in dialogue around uncertainty focused partially on making the uncertainty and assumptions more explicit to improve the potential usability of the information and partially to communicate with decision makers to explain what is known and unknown. The strategy is that communication will help potential users realize that climate information, though uncertain, is usable.

This brings us back to examining uncertainty as a barrier. The two groups examined in this study illustrate the difference in two approaches: (a) uncertainty without communication (i.e., unmanaged) and (b) uncertainty with communication (i.e., managed). For non-clients, row (A) in Figure 5.2, uncertainty without interaction or communication became a barrier to information use. For clients, row (C) in the figure, uncertainty in the science was not an impediment to information use. Interaction with RISAs helped information users manage uncertainty in the information, leading to more information use. This explanation seems to support Lemos & Rood's (*in press*) argument that interactive research would help potential climate information users given the complexity and uncertainty of climate change models.

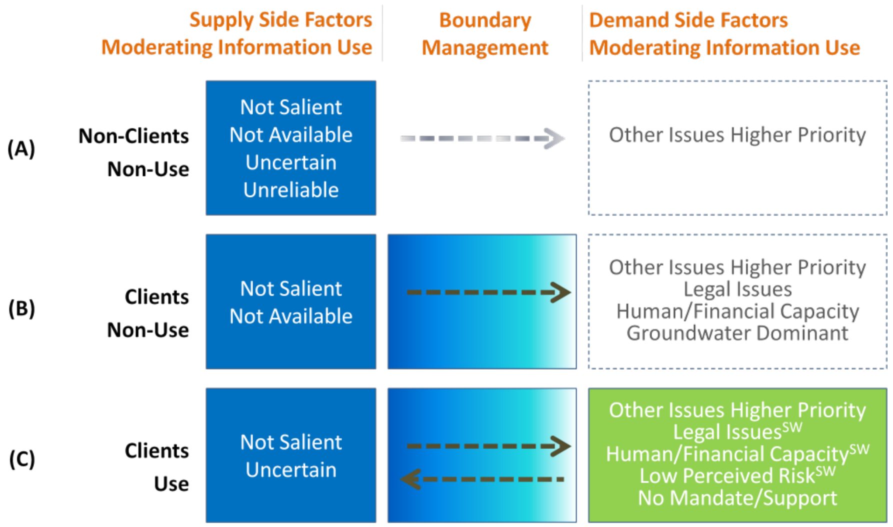


Figure 5.2 Boundary management affects on barriers to information use.

Another interesting example of a barrier on the supply side is salience. Researchers have shown salience is important for information use (Cash *et al.* 2003). Specifically, information that is relevant to the user and in the right format is more likely to be used. However, it is also possible that relevant and useful information does not get used because potential users may not be familiar with the information or may not know how to integrate the information into their decision making. Again, interactive research approaches offer an advantage wherein relevant information that might be useful is made usable through two-way communication and interaction that enable iteration between producer and user to establish how such information might usefully inform decision making.

Figure 5.2 provides an illustration of how boundary work moderates lack of salience. First, in (A), non-clients reported information is not salient. There was no interaction with a RISA, and the information went unused. Next, row (B) shows the condition in which clients too reported the information was not salient. In this case, interaction with the RISA was infrequent, and communication was one-dimensional, minimizing the opportunity for translation or mediation that might lead to information use. Lastly, row (C) illustrates the situation in which clients still perceived that information lacked salience. However, given better communication between the RISA and the stakeholders, what was a barrier in (A) and (B) became manageable in (C).

Up to now, boundary management of supply side factors such as information salience and uncertainty has dominated the discussion. However, demand side factors also impeded or limited information use among clients and non-clients. For example, other issues taking higher priority was a barrier for both groups. This barrier can be interpreted to mean the effort or time required to obtain climate information had a lower priority than other issues, such as keeping the system up and running by performing required maintenance, meeting regulatory obligations, etc. For non-clients shown in row (A) in Figure 5.2, other issues taking priority was the nail in the information-use coffin. On top of the list of barriers on the supply side that must be overcome and with no apparent interaction with an information provider like a RISA to aid information use, the lack of demand for information due to prioritization (and likely other factors not reported) translated in practice to a lack of information use. This can be contrasted with the impact of the demand side barrier for clients. For clients, other issues taking higher priority was one among several reported demand side barriers that had to be overcome. As shown in Row (B), which illustrates clients not using climate information, demand and supply side barriers impeded information use. However, in Row (C), which illustrates clients that used information, demand side barriers did not impede information use. A principle difference between (B) and (C) is the improvement in boundary management work between the RISAs and the clients, which facilitated information use in spite of demand and supply side barriers.

5.5.2 Moderating Information Use: Drivers

In this section, drivers moderating information use are examined (see Table 5.16 for reference). Here, too, boundary management helps drive information use among clients and non-clients. For example, two-way communication and interaction act as important determinants of information use among clients, and interaction acts as an important determinant of information use among non-clients. A comparison of non-clients who did not use information with those who did reveals collaboration with RISAs accompanies information use, supporting the importance of interaction as a condition of RISA information use. Another important condition of information use was having salient, usable information. As learned from the earlier discussion on supply side barriers, boundary work often helps information become salient and usable. In this case, the information was reported to be salient and usable and was ultimately used by clients. Unfortunately, data limitations precluded measurement of these supply side drivers among non-clients. Having salient and usable information was important for clients' information use, and interaction is important for both clients and non-clients.

Table 5.16 Drivers to information use among clients and non-clients.

	Water Managers Using RISA Information	
	Clients	**Non-Clients**
Product Drivers	Salience Usable Information	DNM DNM
Process Drivers	Long-term Relationship Two-way Communication	Collaborative Interaction Two-way Communication
Context Drivers	Information Seeking Collaboration Endangered Species/Water Climate Risks/Vulnerability Commitment to Planning Value Research Human/Technical Capacity System Size (Population Served) Surface Water Source Reliable Water Supply[SW] Commitment from Upper Mgt.[PNW]	Information Seeking Collaboration Endangered Species/Instream Experience Drought Use Climate Proxy System Size (Population Served) Distance from RISA

DNM = Did Not Measure; [SW] – Driver prevalent among Southwest clients.; [PNW] – Driver prevalent among Pacific Northwest clients.

Now, it is important to better understand how the demand side context conditions information use for both groups. To do so, observed similarities and differences between both groups had to be considered. Similarities on the supply side (i.e., salient and usable information) and similarities with boundary work (i.e., two-way communication and interaction) have already been described. These factors are illustrated in Figure 5.3. On the left are the supply side factors for both non-clients, row (A), and clients, row (B). The middle column illustrates boundary spanning, process-factors for both groups, while the right side of the figure shows the demand side factors conditioning information use.

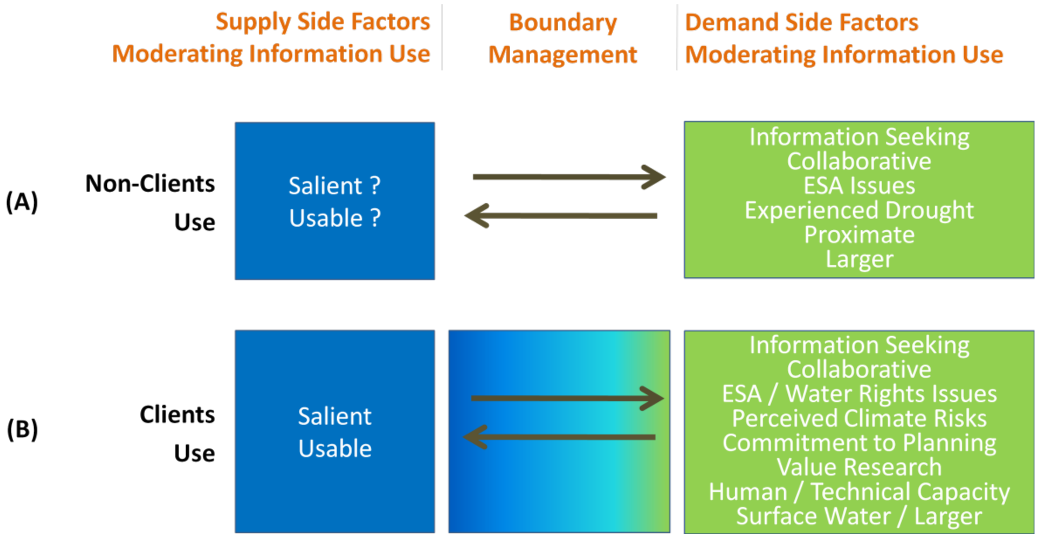


Figure 5.3 Boundary management and demand side drivers affecting information use.

Figure 5.3 enables an examination of the similarities and differences on the demand side, in the right column of the figure for non-clients, shown in row (A), and clients, shown in row (B). The first two factors, both behavioral characteristics, were shared by both groups: (a) information-seeking behavior and (b) collaboration. This suggests whether or not the water managers are clients: if they tended to seek outside information and collaborated with universities or other outside entities, they were more likely to use RISA-generated climate information. This is somewhat surprising, given that this behavior suggests a different culture at work than has been described previously in the literature. The culture of water managers has been described as conservative and insular. Instead of using outside climate information, water managers valued routine, established practices, and local knowledge (Callahan *et al.* 1999; Pagano *et al.* 2001; Pulwarty & Redmond 1997; Rayner *et al.* 2005). This suggests that some water managers may be more willing to use outside information and to engage with others outside of their organization than previously thought. This discrepancy between what was known about water managers and what was observed here may be a function of differences in the study populations. Then again, these differences may be due to the influence of increasing awareness of climate change or increasingly information-centric water management approaches such as adaptive management or integrated water resources management. On the other hand, it could be that the interaction with the RISAs played a role.

Organizational culture has been argued to be a factor moderating climate information use. Lemos (2008) found that a more flexible, less accountable organization enables water managers to act more freely than they might otherwise. This less-constrained culture supports a degree of risk-taking that improves the likelihood of forecast use. Our understanding of RISA client information use in the PNW suggests that a supportive organizational culture facilitated information use. When upper level management supported the use of climate information by PNW RISA clients, the support facilitated information use. However, instead of less accountability paving the way for risk-taking and information use (Lemos 2008), what was found here was an accountable but supportive organizational culture that facilitates information use. Differently from the managers studied by Lemos (2008), who had a high level of discretion coupled with lower accountability, water managers in the PNW also exhibited a high level of discretion in using climate information but did so with the backing of the organization.

Another explanation for this observed difference in culture may be that water managers sought information because they perceived some vulnerability to their water resources. This vulnerability may come in the form of past experience with drought or through other threats such as competition for water supplies with other potential users, including the need for instream flows. Both clients and non-clients shared these indicators of resource vulnerability from climate variability and from competition (i.e., endangered species and/or water rights). These vulnerabilities may prompt water managers to seek more information to quantify their potential exposure. This information may be in the form of forecasts, which both groups used at high rates, to tree ring reconstructions, which was seen regionally among SW clients and non-clients using RISA information. On the other hand, it may be climate change information, which was seen at a higher rate among PNW clients and non-clients. Information use by clients seemed to be motivated in large part because of the potential effects of climate change on endangered species. Climate vulnerability and change affect endangered species because instream flow amounts are negotiated and often mutable if conditions are not sufficiently protective. For example, if future climate change affects the stream temperature or timing of flow, instream flows might be increased to maintain suitable conditions for endangered species. The potential increase in the amount of water required for instream flows means water users who wish to withdraw water might face more restrictions. Water rights issues might also be affected by climate variability and change. Water is allocated based on historically available flows. If those flows lessen due to the impact of climate change or longer and more severe drought than has been experienced in the recent past, then water rights holders have some risk. This latter impact seemed to play a larger role in motivating interest in climate change for SW water managers. Taken together, results suggest these demand side vulnerabilities played an important role in driving information use among clients and non-clients.

Up to now, the focus has been on behavior (i.e., information seeking and collaboration) and perceived or actual vulnerabilities and/or risks to water supplies (i.e., perceived climate risks, experienced drought, endangered species/water rights) that facilitated information use. These factors have been discussed as potential reasons why these water managers seemed open to using climate information. The discussion revealed that context factors motivating information use among clients and non-clients were similar.

Now physical characteristics of the system, such as (a) system size, (b) water source, or (c) location that affect information use will be discussed. Both clients and non-clients who used RISA information generally hailed from larger systems. This result was not entirely unexpected since gathering and using information requires some resource input—time, certainly, and perhaps money. Larger systems do have more resources available than smaller systems (recall the correlation between budget and system size for non- clients), and larger systems may be more vulnerable because they serve more people. In fact, non-client RISA information users were, on average, two orders of magnitude larger in terms of population served than non-client non-RISA users. However, the subset of clients who responded to the survey oversaw local water systems that were, on average, an order of magnitude larger than non-clients who used RISA information. This suggests a difference in system size between clients and non-clients who used RISA information, which may reflect a threshold to being a RISA client. It may signal that, generally, only very large, local systems have sufficient capacity available to interact with RISA scientists. Clients reported having staff that interacted with RISAs and technology that facilitated integration of new information. However, in the case of clients from smaller systems using RISA information, these systems were likely more sophisticated than others in their size range. The difference in size is probably not the only factor differing between clients and non-clients, but it appears important. The difference in clients and non-clients notwithstanding, there was an association between system size and information use that sets RISA information users apart from non-RISA users.

One glaring difference between clients who used RISA information and non-clients who used RISA information was water source. Clients overwhelmingly relied on surface water sources, while non-clients who used RISAs relied on both surface and groundwater. For this latter group, water source was not significantly associated with RISA use. This difference may simply be associated with the order of magnitude difference in size that seems to set clients apart from non-clients. Larger water systems tended to rely on surface water, which was typical not only in the regions studied here but also across the United States (EPA 2002).

The last demand side factor to be discussed is proximity. Distance matters for non-clients who used RISA information, which means that systems located physically closer to the RISA were more likely to use RISA information. For clients—the mix of utility water managers and county or state water managers—distance matters, but it was moderated by the relationships clients form with the RISAs. This seems to suggest, as discussed previously, that once a stakeholder relationship was established, it could be sustained across greater distances. However, when considering only clients who were water managers of large utilities, proximity was more constraining. This subset of clients was, on average, 50 miles closer than non-client RISA users. Distance seemed to matter most among RISA users due to collaboration. For example, non-clients who reported some level of collaboration with RISAs were, on average, 53 miles closer than non-clients who reported using RISAs as an information source.

Thus far, this discussion has focused on (a) clients and non-clients as aggregated groups across regions and (b) analyzing aggregated RISA use instead of looking at RISA use by region. Aggregating the groups in this manner facilitated the analysis of how factors moderated information for clients and non-clients and enabled testing of the effects of boundary management. Results indicated that boundary management seems to be most important for mitigating barriers to information use. The various differences between clients and non-clients and users and non-users of RISA information have also been examined. In examining drivers of information use, surprising similarities between non-client and client RISA information users emerged. Among the drivers of information use, boundary management seemed to be most important for facilitating collaboration. Next, regional differences in collaboration and the potential implications of those differences are explored by disaggregating the groups and thinking more about each RISA and region.

5.5.3 Regional RISA Models and Impacts on Information Use

Differences between the RISAs and information users emerged during the analysis of the factors moderating information use. For example, clients in the SW were more inhibited by (a) legal issues, (b) human and financial capacity constraints, and (c) a lower perception of climate-related risks than clients in the PNW. On the other hand, clients in the PNW were better able to use information when upper level management in the organization supported that use. Also, in the PNW, endangered species issues drove information use, whereas in the SW the more important legal issue motivating information use was water rights. Among the broader population of water managers, endangered species and drought were relatively more important predictors of information use in the PNW, whereas in the SW, use of climate proxies was a better predictor of information use. Potential explanations for these differences in predictive importance have already been discussed; what is more pressing here is how these differences relate to variation in (a) rates of information use and (b) interactions with RISAs across regions.

First, differences in the rate of information use among clients and non-clients are examined. The high rate of information use of clients (84%) has already been presented. However, the regional difference in rates of information uptake between clients in the PNW and the SW (94% vs. 77%) has not yet been discussed. While this difference is not significant, an exploration of it may reveal something about the interactive research approaches of the RISAs or perhaps of the information itself. For example, lower client information use in the SW may be, in part, attributable to interaction. Analysis of the interview data indicated a regional difference in the barrier infrequent interaction. More of those interviewed from the SW than the PNW described how infrequent interaction impeded information use, which may suggest that the SW clients interacted with CLIMAS at lower rates than PNW clients interacted with CIG. Interestingly, this difference in interaction held among the broader population of water managers. Water managers in the PNW collaborated with CIG to a greater degree than they relied upon CIG as a source of general or climate information (χ^2 (2, N=517) =9.60, $p < .01$). The pattern of RISA use was different in the SW, where more systems reported using CLIMAS for general or climate information rather than collaborating with CLIMAS. To help understand this regional difference in collaboration versus information provision, the interview data were again mined for clues that might explain why such a stark difference exists.

One difference that emerged in the re-examination of the interview data was the type of information being produced. While both RISAs were engaged in stakeholder-driven research and both produced forecasts, other end products differed. In the PNW, much of the work concerning water resource management focused on downscaling climate information in addition to forecasting. The production of downscaled climate information in particular seems to require more collaboration in the process of information generation, a finding born out in the interviews as individuals described interacting with CIG to produce system-specific or regionally specific climate impacts information. These interactions often involved a process of mutual learning and repeated interaction over a sustained period of time. CIG also engages in semiannual water forecast meetings, which appear to be more about brokering information. This type of engagement is not as intense from the perspective of stakeholders. That said, PNW clients more often described collaborative relationships with CIG than broker-type relationships. On the other hand, clients in the SW often described a relationship whereby CLIMAS provided important scientific information useful to water managers through collegial interaction that involved mutual understanding but had a more consultative than collaborative tone. SW clients described using forecasts and tree ring information and communicating with CLIMAS, but this communication was generally less intensive than that described by PNW clients.

In summary, interview data suggested that CLIMAS is more of a trusted information provider or information broker, while CIG employs more of a collaborative, co-production role with clients. These differences help explain why CLIMAS may have more visibility among the broader population of water managers than CIG, given the different roles each RISA plays vis-à-vis stakeholder relationships in their respective regions. However, the differences might also speak to the underlying processes of information dissemination between information products. The more collaborative, lower level visibility in the PNW might reflect the slower, challenging nature of climate change information uptake versus the more mature uptake of tree ring reconstruction information. The uptake of tree ring information was, at one time, challenged by the novelty of the information application and the uncertainty inherent in the reconstructions (CLIMAS scientist, telephone interview, November 7, 2008; CLIMAS scientist, telephone interview, November 4, 2008). Now, use of tree ring reconstructions is more routine. In contrast, observations in the PNW suggested a steep learning curve around the use of climate change information, slowing down use. It is possible that the steepness of the curve will eventually diminish as more and more water managers start incorporating climate change information. On the other hand, perhaps uptake of climate change information with all of its complexities and uncertainties will be slower and will require consistent and prolonged collaboration with a RISA or another information provider.

With the above discussion in mind, it is appropriate to examine differences in rates of information use among non-clients within and between regions. As mentioned previously, RISA information use among water managers was reported as follows (see Table 5.5): 31 out of 536 water managers used RISA information in the PNW, while 19 out of 131 water managers used RISA information in the SW. From the data, it is apparent that the proportion of RISA use among non-clients in the PNW was lower than among non-clients in the SW (5% vs. 13%, χ^2 (1, N=660) =8.68, $p < .01$). The data also indicate that more systems in the home state of the RISA (Washington for the PNW and Arizona for the SW) reported using the RISA than other states in the RISA region: PNW=χ^2 (2, N=532) =7.28, $p < .01$ and SW=χ^2 (1, N=128) =6.57, $p < .01$. Moreover, rates of non-client information use were lower for the states in the PNW than states in the SW. Figure 5.4 illustrates these differences by depicting the number of respondents who use the RISA—CIG in the PNW and CLIMAS in the SW—out of the total number of respondents for each state. If clients who returned surveys were included in the figures, the home state bias would increase in both regions.

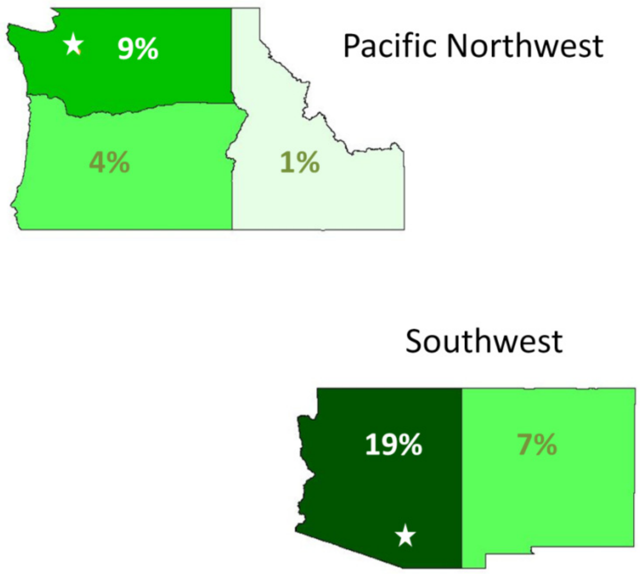


Figure 5.4 Information uptake and the home state bias.

A number of factors likely contributed to the difference in information uptake between regions and within regions, some of which have already discussed, including the fact that RISAs can be quite different from each other. Each RISA was purposefully designed to meet regional information needs with a unique set of staff, level of funding, and expertise. Additionally, while the core mission of a RISA—to provide usable, place-based research that meets the needs of regional information users—is the same, the philosophy and mix of approaches used to achieve that mission differ. These differences in approaches may affect information use. Similar to what McNie *et al.* (2005) reported, the differences in collaborative versus consultative approaches did not affect information use as much among clients, since both RISAs achieved high rates of information use among their clients. However, the differences did appear to affect rates of information use among the larger population of water mangers. The difference in information uptake may be attributable to the particular approach used by the RISA or to the information itself that might necessitate the use of particular approaches. While no one relationship type—collaborative or consultative—appeared qualitatively better or worse than the other in achieving high rates of client information use, the higher rate of collaboration in the PNW may actually be costly in terms of extending the reach of the RISA among the broader population of water managers. However, the collaborative approach may be important and necessary for the conveyance and use of climate change information more than the use of forecasts or for general information. This suggests that if other RISAs work to model CIG's approach to conveying climate change information, they too may face slower rates of uptake, at least initially.

Having explored these regional differences quantitatively and qualitatively, the next step is to explore, from a theoretical perspective, differences in RISA approaches. A 2005 workshop convened to explore how RISAs reconcile the supply and demand for science found that RISAs employ a number of different approaches to provide usable information, including (a) stakeholder driven research, (b) information brokering, (c) participant/advocacy, and (d) basic research (McNie *et al.* 2005). Rather than using a single approach, RISAs employ "a number of approaches at different times depending upon the particular context of the problem" (McNie *et al.* 2005, p. 5). This rationale for using different approaches suggests RISAs are reflexive and adaptive—and indeed they are—but it misses a key aspect: RISAs generally employ a programmatic strategy and use these varying approaches to achieve over-arching goals. That is not to say that there is not an element of opportunism or that the unpredictable mix of factors does not require a level of adaptation. Rather, this mix is more purposeful and strategic. Lemos and Morehouse (2005) captured this idea perfectly:

> "Despite their focus on application, the reality of regional assessments is that they require a combination of knowledge-driven, applied and interactive science which strikes the delicate balance between what we need to know to understand complex problems and what stakeholders perceive to be their immediate needs for making decisions (p. 58)."

They proposed a model of interactive research, iterativity that aims to encompass these different research approaches within the three components of the iterativity model: (a) interactions between stakeholders and scientists, (b) interdisciplinarity, and (c) usable science. In this model, successful iterativity involves maximizing each component to achieve high levels of innovation and greater societal impact (Lemos & Morehouse 2005). Innovation is indicated by knowledge use.

This model was explored using CLIMAS[1] and CIG regional water manager data collected for this study including, outcomes of interest—higher innovation and greater societal impact. On the surface, both RISAs appeared to be engaged in successful iterativity with their clients, given the high rates of information use and, presumably, societal impact. This success was achieved in the face of qualitatively less than optimum rates of interaction among some clients in the SW. Perhaps the explanation here is the same as what was proposed earlier: the boundary management efforts of the RISAs in sustaining higher or lower levels of interactions among clients nonetheless lead to knowledge use in spite of differences and distance. Unfortunately, with a small sample size, it is difficult to parse out differences in interaction and the impact on information use. However, these differences can be explored in more detail with non-clients who used RISAs. Since the underlying similarities between clients who used RISAs and non-clients who used RISAs has been established, it is now possible to extend and test the Iterativity Model using this larger population.

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[1] Although CLIMAS was the inspiration for the original theoretical model, it was never tested using independent empirical data.

Proceeding with the analysis required the ambitious assumption that the Iterativity Model that describes scientist-stakeholder relationships aimed at producing integrative, usable science encompasses and may be used to describe non-stakeholder-scientist/RISA relationships as well. Unfortunately, completing this test of the model was stymied somewhat by the difficulty involved in measuring societal impact and innovation among non-clients. Furthermore, the application of Lemos and Morehouse's (2005) indicators of successful iterativity was limited since information that non-clients use is unknown. To get around this limitation, the focus was on one indicator of successful iterativity: level of innovation, measured by the level of RISA information use.[2] Second, the focus was on available quantifiable measures of interaction, a component of the Iterativity Model. The Iterativity Model suggests that higher levels of interaction (all other components being equal) should lead to higher iterativity, measured here as more information use. From the previous discussion of clients, qualitatively higher rates of collaboration among PNW clients marginally improved rates of information use among PNW clients compared to SW clients. However, considering the broader population, a different outcome emerged. The previous discussion of non-clients revealed more collaborative interaction in the PNW and less reporting of collaborative interactions in the SW. According to the Iterativity Model, this suggests that higher rates of information use should be expected in the PNW than in the SW. However, in fact, the reverse was true: there was comparatively more information use in the SW than in the PNW, which is is illustrated in Figure 5.5.

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[2] Lemos (2008) equates forecast use as an indicator of innovation adoption.

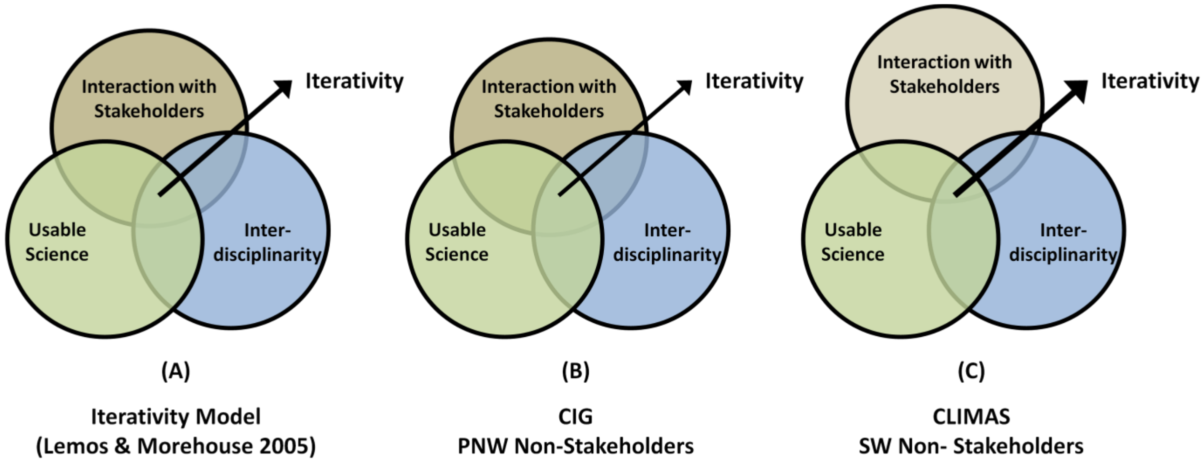

Figure 5.5 Iterativity model as originated and as applied to non-stakeholders

Figure 5.5 first depicts the Iterativity Model (Lemos & Morehouse 2005) in (A). Then, in (B), the interaction bubble is shown slightly lower, and the iterativity line is thinned, reflecting information use observed among PNW non-clients. Finally, (C) depicts the interaction bubble slightly higher and the iterativity line thickened, reflecting information use observed among SW non-clients.

The results illustrated in Figure 5.5 in (B) and (C) may simply reflect poor or incomplete measurement or a biased response from non-clients. For example, it was not possible to measure interdisciplinarity or usable science, the two other components of iterativity, nor was it possible to measure societal outcomes among non-clients. These weaknesses in measurement notwithstanding, the difference in anticipated outcomes was worth exploring, given the significant overlap between client and non-client RISA information users. One explanation is that the original model did not adequately capture the different types of interactive research approaches RISAs use that result in variance in the interaction component and in overall RISA use.

Now, returning to the client context enables a closer look at information use, an indication of successful iterativity. In so doing, the variance in information use is explored along with the variance in the range of interaction. By establishing more clearly this association between the range of information use and interaction, it may be possible to devise a way to incorporate this variation in iterativity, measured by interaction and information use. Returning to the interviews, data indicated that, while interviewees exhibited a high rate of RISA use, the nature and extent of interviewee interactions with the RISA and use of RISA information varied. On one side were clients who had limited interactions with RISAs and limited information use, and on the other side were interviewees who had extensive and sustained interaction and used information tailored to their specific application or system. A set of interviewees also fell in between these two extremes. On the low end of information use, clients reported receiving infrequent emails, attending one or more conferences or presentations, or using RISA information accessed from a website. Clients who reported moderate information use indicated they were actively seeking climate information, learning about climate variability and/or climate change, and using climate information in planning. Some information users reported funding RISA research applicable to the specific interests of the water system, including climate change modeling or tree ring reconstructions, and then using that information in planning or in decision making for infrastructure projects. These information users represented the highest end of information use, up to and including contractual type relationships with the RISAs, to fund research specific for their needs. A way to conceptualize RISA information among clients is as a spectrum ranging from limited or no use to substantial and tailored information production and use (see Figure 5.6).

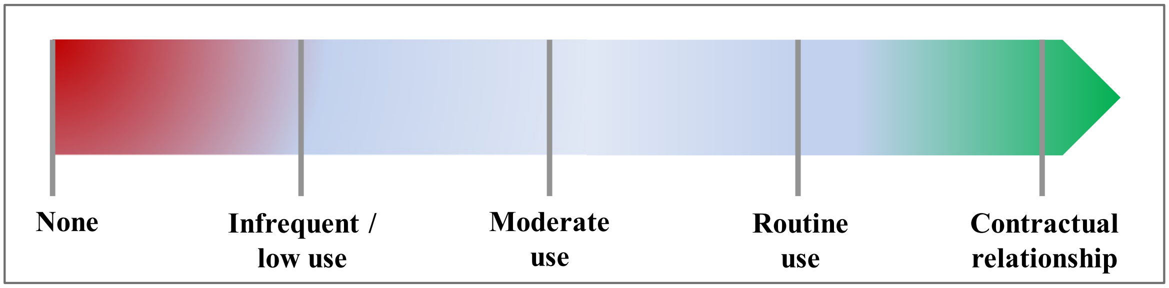

Figure 5.6 Spectrum of information use.

Another way to think about information use by RISA clients is to consider not only the spectrum of uses but also the intensity of interaction. Interviewees who reported more substantive information use also indicated they had higher levels of interaction with the RISAs, contributing to higher use. Conversely, interviewees who reported less frequent interactions also reported using information less intensively. This result suggests an association between the intensity of interaction and the intensity of information use. This association supports the fundamental tenants of the Iterativity Model for stakeholders but suggests building in a component that accounts for intensity of interaction and information use that was reflected in non-clients' use of information. This variation component better reflects differences observed between PNW and SW clients that was not able to be quantified due to limitations in the number of interviewees but was quantified in the larger population of non-clients using survey data. When comparing across regions, it was in this larger population that lower levels of interaction were associated with comparatively more information use overall. Given these findings, variation in interaction and information use might be conceptualized as shown in Figure 5.7.

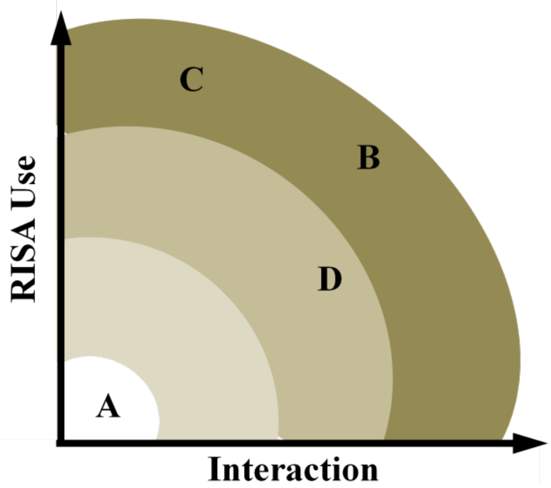

Figure 5.7 The relationship between interaction and RISA use.

The original Iterativity Model describes two of the four conditions shown in Figure 5.7. First, Position A corresponds to low interaction (a component of Iterativity) and low information use, while Position D corresponds to the opposite condition: high interaction (Iterativity) and high information use. Figure 5.6 adds variation in interaction as a means to explain the two other conditions shown: Position C illustrating lower interaction but higher rates of RISA Use, the condition observed in the SW, and Position D illustrating high interaction but lower rates of use, the condition describing what was observed in the PNW. Positions C and D in the figure attempt to capture differences in outcomes between a consultative approach and a collaborative approach, respectively. Of course, this conceptualization is likely imperfect and incomplete, given the many unknowns regarding what information was used by non-clients and the ultimate impact (i.e., societal outcome) that information had on the organization or broader community. One of the challenges of advancing the Iterativity Model further is that the model focuses on aspects of information production. While focusing on information production is important, it is limited in that it does not factor in the information use side of the equation.

A closer examination of client information use may help conceptualize the mechanisms that work to reinforce or counter information use. Thus far, the focus was the examination of barriers and drivers of information use and the role of the RISAs in managing the boundary between science production and use. Barriers were examined to understand how they work in concert or in opposition. However, these observed relationships have not yet been conceptualized. This examination and conceptualization are the focus of the next chapter along with an exploration of other factors (e.g., external influences) that may play a role in information use various scales. Initially, the focus is on clients who are water managers of utilities. The focus then shifts up in scale to examine county- or regional-level water managers and, finally, to state-level water managers who use RISA information. Once that is complete, the role RISAs play in contributing to more effective knowledge-action systems is examined.

Chapter 6

Outcomes Analysis: Building Resilience through Knowledge-Action Systems

The Iterativity Model describes a process of information production theorized to promote increased information use and improved societal outcomes. In the previous chapter, one of the components of the model, namely interaction, was explored and shown to lead to higher rates of information use among RISA stakeholders that directly benefit from repeated and close interface with the RISAs. However, the Iterativity Model primarily focuses on information production within RISAs, paying less attention to the exogenous processes that might influence information uptake by potential users. Now it is appropriate to explore in more detail the mechanisms of information uptake within each region focusing less on the process of information production and more on the organizations and environments within which information is used. In other words, the intent is to learn more about the information use space from the user perspective through analysis of in-depth key informant interviews to examine mechanisms within and outside of organizations that interact to promote or inhibit information use. This more expansive view, from the user perspective, allows not only for better understanding of the interplay of internal and external factors shaping information use but also for the exploration of alternative explanations of higher or lower levels of information uptake.

Moreover, a further aim is to understand the implications of information use for decision making, including its organizational and broader societal impacts. The focus is to explore the specific ways in which RISA information improves decisions that, in turn, affect organizations and society's response to climate-related impacts.

6.1 Theoretical Framework

6.1.1 Information Use and Resilience Potential

Water management organizations have learned from past experiences and have adapted practices in response to a range of resource stresses and planned change. The general strategy has been first, to buffer or minimize the impact of perturbations on their systems to prevent crises from overwhelming their capacity to respond (Berkes & Folke 2000; Gunderson *et al.* 2002); and second, to anticipate and enact planned change. When the system is operating within normal ranges as is presumed under stationarity (Milly *et al.* 2008), these strategies work well. But, when perturbations actually or are perceived to have the potential to push beyond expected ranges, water managers look to quantify the limits of these perturbations to adjust management response and again limit the potential for failure or crisis. Natural climatic variability has long required water managers to institute buffers against the threat of too little or too much water. Water managers have buffered against this natural climatic variability through the use of structural (e.g., dams, levees, etc.) and more recently non-structural (e.g., conservation) measures. But the threat of climate change, increasing competition for water supplies, and increasing climate variability are collectively pushing water managers to consider new limits beyond what they have experienced in the past. Water managers use information to quantify these new limits and to inform a range of potential responses to buffer against these new collective perturbations to the resource.

This pattern of stress and response is observed among the water managers interviewed for this study. Here water managers' use of information is examined in more detail using the idea of buffering adapted from Berkes & Folke (2000). The idea of social systems (i.e., water management organizations) buffering against disturbances is used to create the following framework for analyzing local water resource manager's information use: perturbations, the organization, and stabilizers. Perturbations refer to stressors external to the organization that are internalized as risks to the water resource. Stabilizers refer to the responses enacted by the organization to buffer against risks from destabilizing perturbations. Finally, the organization refers to the water management entity that interprets and responds to external stressors. Water managers within the organization use information to support stabilizing responses. The first step in the analysis is to examine the framework as described and the mechanisms for information uptake across water managers aggregated by regions. The next step is to then take a closer look at how information is be used by organizations to undergird policies that increase resilience of water management systems.

Resilience refers to the "magnitude of disturbance that can be absorbed" before a system changes state and the "capacity for adaptation to emerging conditions" (Adger 2006). Building resilience is one strategy to buffer against disturbance, or in this case perturbations to water resources. Somers (2009) suggests that organizations can build resilience through planning but he also suggests there are characteristics of organizations that are indicative of resilience potential. These organizational characteristics include: the perception of environmental risk, seeking information about the environmental risk, balanced decentralization, and planning (Somers 2009). In the previous chapter, results indicated clients who use RISA information are aware of climate vulnerability, seek information, and are committed to planning. This suggests that the water utilities that engage with RISAs possess a number of important indicators of organizational resilience potential. Other indicators of organizational resilience potential shared by these systems include human, technical, and financial capacity and a culture of collaboration. While these systems seem to possess key indicators of organizational resilience potential, it is important to determine how RISA information used in planning may contribute to resilience, understanding that information alone can do little without an institutional structure to implement response. It is in the planning efforts that shape potential responses where RISA information plays a critical role in building resilience potential.

6.1.2 Knowledge-Action Systems

Lemos & Morehouse (2005) assert that successful Iterativity leads to "higher levels of innovation and greater societal impact" by enhancing the linkages between science and policy ultimately leading to the “development of more effective policies for addressing regional climate variability and change.” In Chapter 5, the Iterativity Model was explored in the context of RISA information use by water resource managers in the Southwest and Pacific Northwest. The focus was on local water managers’ use of climate information produced by RISAs as an indicator of successful Iterativity. In this Chapter information use and outcomes will be explored in more detail at the local level by examining the mechanisms of information uptake by local water managers in the PNW and SW. The analysis reveals information use improves systems’ responses to climate and other perturbations to water resources making these systems more resilient to climate variability and change. The next step is takes the analysis a bit further to explore how RISAs’ boundary spanning work helps mobilize science and technology to enhance county and state efforts to buffer against climate variability and anticipated climatic change and how RISAs contribute to effective knowledge-action systems.

Cash *et al.* (2003) proposed a framework for building effective knowledge-action systems that would effectively mobilize science and technology for sustainable development. They suggest that effective knowledge-action systems manage the boundary between knowledge and action through communication, translation, and mediation – functions that can be “effectively performed through various organizational arrangements and procedures…institutionalized in boundary organizations…that act as intermediaries between the arenas of science and policy” (Cash *et al.* 2003, p. 8089). As demonstrated in this research and by others the RISAs in their practice of successful Iterativity are boundary organizations (Lemos & Morehouse 2005; McNie *et al.* 2005; McNie 2008). The next step is assess RISAs’ contributions to effective knowledge-action systems using the knowledge-action framework proposed by Cash *et al.* (2003) only here applied to actions to build resilience to climate variability and change. This evaluation also includes an assessment of potential constraints that may limit the effectiveness of those systems in achieving desirable policy outcomes (i.e., the development of policies to buffer against climate perturbations) across multiple scales. Importantly, the analysis aims to: (1) demonstrate RISA’s critical role in building effective knowledge-action systems for resilience and (2) add to the theory regarding requirements for effective knowledge-action systems.

6.2 PNW Water Resource Management & Information Use

6.2.1 Local Level Analysis

Five water managers were interviewed from PNW water utilities that varied in size with the smallest serving less than 100,000 people and delivering less than 9 billion gallons per year to the largest serving more than 10 times as many people and providing nearly 14 times as much water annually. The five utilities are governed by elected bodies consisting of a mayor and city council, mayor and commissioners, or an elected board. Differences in size and governance structure belied commonalities. These commonalities are categorized according to the analytical framework: perturbations, management responses enacted to buffer against known or anticipated perturbations, and information used to quantify the risk and inform the management response.

6.2.1.1 Perturbations

A common stressor experienced by all five stakeholders interviewed from the PNW is managing water to ensure supplies are available for growth while leaving sufficient instream flows to provide necessary habitat for endangered salmon. All five water managers withdraw water from surface water bodies that provide habitat for endangered salmon and so must manage to ensure aquatic habitat, critical for salmon reproduction and survival, is protected during certain times of the year. This requirement normally entails the creation and implementation of Habitat Conservation Plans to protect endangered species at the source (telephone interview, June 30, 2009). Protecting endangered species can retroactively impact existing supplies as well as impact potential new supplies if instream flows are implemented and/or adjusted. For example, one PNW water manager expressed how endangered species issues must be managed when considering new sources:

> *The Utility deals with an increasing number of issues related to the development of new supplies and their impact on aquatic eco-systems, which in this part of the world is dominated by salmon. – telephone interview, May 26, 2009*

For existing water resources endangered species protections may influence water rights if instream flows are adjusted either because of climate or habitat concerns or because of previously non-quantified water rights. For example, long non-quantified Native American water rights are now undergoing adjudication in the PNW and elsewhere:

> *Congress signed Treaties with the Native American tribes in 1854 and 1855, which gave them federally guaranteed water rights for fishing and hunting, predating the Utility's water rights. But prior to the mid-1970s little was done to mitigate impacts to the Native American tribes. It wasn't until the Supreme Court affirmed those Treaty Rights in 1974 and determined that tribes had a right to half the harvestable fish did utilities know what was to be used to determine the amount of Treaty Water Rights reserved for Native American tribes. So, since Native American tribes had fishing rights, they also had the right for the ecosystem to provide for the growth and development of fish, which gets into water rights. When the Utility wanted to build a second pipeline to roughly double the supply of water, the Utility had to resolve past damage claims and establish guarantees over future supplies.- telephone interview, May 26, 2009*

These adjudications modify existing water rights and change conditions for water mangers. Endangered Species Act listings have pitted demands to protect ecosystem function to preserve and restore anadromous fish species against human uses of water resources.

> *Washington is widely viewed as a very wet State; and, it is a wet state on an annual basis. But, there are challenges during the summer months when municipal water supplies and agricultural water supplies face higher demands and there are higher demands for instream flows to protect fish. So, setting instream flows for the summer months is really critical for the Utility and for the area. – telephone interview, May 29, 2009*

Competition is not limited to humans and fish. Rather, water resource management requires balancing multiple uses and needs such as ensuring regulatory compliance, balancing flood risk with low end of season flows, and balancing flood risk with hydropower generation needs. Low flows further complicate allocations between the various uses of water that makes achieving a balance between hydropower, irrigation, municipal water supplies, flood control and habitat protection much more difficult.

Balancing multiple uses is also made more challenging by over-allocated water supplies and by climate variability and change. When most people think about the climate in the PNW, they think about places like Seattle where the imagery is one of grey skies and constant rain. In reality except for the coastal areas, which generally receive more than 49 inches per year, much of the PNW is actually quite arid receiving less than 15 inches per year (Moreland 1993; Mantua *et al.* 2007). Historical climate and tree ring data indicate the interior PNW routinely experiences persistent droughts and is actually among the more drought-prone regions in the continental United States (Knapp *et al.* 2004). The Pacific Decadal Oscillation (PDO) and El Nino/Southern Oscillation (ENSO) play a role in interannual and decadal scale variations in snowpack and streamflow in the PNW (Mantua *et al.* 2007). The risk of drought increases during ENSO and PDO warm phases, while cool phases see increased risk of flooding.

Recent years have been much drier (Snover & Mantua 2007) contributing to droughts in 2003, 2004, and 2005 (Mote 2006). The 2005 drought left 1,400 farmers in the Yakima Valley's Roza Irrigation District with two-thirds less water than they normally receive and prompted Seattle to ask residents to conserve to forestall possible summer shortages (Ritter 2005). Water managers in the PNW are sensitive to this natural climatic variability. Unlike drought in the SW, the PNW droughts are generally much shorter in duration lasting normally a single year or season (Hamlet *et al.* 2007). Even so, droughts can cause surprising impacts like the water restrictions mentioned above. Climate change offers another complication. Approximately 50 percent of the water supply in the Northwest depends on snowpack, which is projected to decrease in the future (Ritter 2005). Water managers in the PNW have recognized the risk posed by climate change and most of the larger water systems have sought to quantify that risk using information garnered in consultation with CIG directly or indirectly.

6.2.1.2 Stabilizers and Information Use

Water managers interviewed from the PNW have long paid attention to climate variability in many cases through examination of historical records of stream flow and precipitation. This information was routinely incorporated into short- and longer-term planning and operational decision making to help respond to changing conditions. Examples of forecast information use include:

> *The Utility uses a variety of forecasts (daily, mid-range, 30-90 day climate outlooks), SnoTel readings, stream gages, etc. Forecasts help in operational planning at multiple time scales (day-to-day to several months out). – telephone interview, May 15, 2009*

> *The Utility has always paid very close attention to the historic record because of turbidity and related concerns. The historic record is used in long-range planning and in short-range, annual Summer Supply Planning. The Utility also uses climate variability information in Reservoir Operation's Modeling. Because of the importance of climate variability, the Utility employs a full-time staff person dedicated to staying abreast of climate variability for the Utility. – telephone interview, June 30, 2009*

Droughts and increased competition for existing water supplies led some, but not all, water managers to seek to understand and quantify the potential impacts of climate change through the utility's normal planning process or through a larger regional water supply planning effort. For one water manager, examining potential impacts of climate change was done reluctantly as part of the latter, larger regional planning effort:

> *The utility's administrators were reluctant to deal with climate change issues because the they believed that the water utility had dealt with the range of possible combinations of snow pack and rainfall and weather conditions that led to spring droughts, fall droughts and everything in between already and that these variations would be similar to the impacts of climate change on the water supply. – telephone interview, May 26, 2009*

When the impacts analysis was completed, the utility found very little relative impact on firm yield due to climate change even though 50 percent of their water supply is dependent on snowpack. Another water manager who willingly participated in the regional water planning effort reported that climate change impacts were a long-term issue. Results from the climate change impacts analysis indicated the utility would face moderate reduction in firm yield over the long-term. They used the results as additional impetus for increasing conservation efforts in the near-term and pledged to stay abreast of research on climate change impacts in particular because of the concern that those impacts might result in a change in the timing and amount of flows required for maintaining endangered species habitat. For one utility, examining climate change impacts was done as part of their normal planning process and reflected a larger commitment to sustainability and to leadership on climate change and water issues. Results from the climate impacts study revealed modest impacts. Nevertheless, the Utility used that information to renegotiate long-term wholesale water contracts to reduce Utility liabilities. They also developed additional groundwater rights and began developing non-potable water supplies and water recycling programs and strengthened their conservation programs.

For other water managers, understanding potential climate change impacts on both the supply side (i.e., decreased yields) and the demand side (i.e., increasing peak summer demands) were undertaken as part of a larger strategy to plan for growth and to assess competing demands for water. For these water managers, water supply vulnerability that might be exacerbated by climate change and potential sea-level rise impacts was an important motivator. For example:

> *The Utility is committed to protecting the City's water supplies to ensure sufficient water is available during the summer months even considering climate change impacts and glacial recession. The Utility has used climate change impacts information to determine how predicted temperature, precipitation, and precipitation timing changes will affect water supply diversion ability and reservoir capacity. The information has helped inform the City's position as they participate in negotiating water rights and instream flow issues.- telephone interview, May 29, 2009*

The water manager cited above also indicated a desire to take potential sea-level rise into account around redevelopment of the waterfront area. Unfortunately, except for considering potential sea-level rise in habitat restoration efforts, they have not had much success. Even so, the Utility's efforts are aligned with the larger city-wide effort to address climate change mitigation and to be more sustainable. Water supply vulnerability was also an issue for the last utility interviewed. Recent droughts in 1992, 2001, and 2005 coupled with population growth in the region contributed to water shortages in a normally very rainy part of the PNW. These incidences brought water resource management issues into sharp focus first around climate variability and then around climate change. These events coupled with individual water manager initiatives, internal chain-of-command support, mayoral support, and a larger regional effort propelled the Utility into a position of real leadership on the climate change and adaptation front. To support that effort, the Utility created a Climate and Sustainability group and has multiple staff working on climate change issues within the utility. The two water managers interviewed for this study pointed to examples of leadership at the international, national, state, regional, and local levels including lobbying Congress and the state government, participating in regional climate change assessment efforts, working with associations and other groups on climate change initiatives, and informing research agendas. They also pointed to climate change adaptation efforts within the Utility, taken as a result of anticipated increasing demands and reduced supply resulting from unmitigated climate change. These adaptation efforts included programmatic changes such as increasing conservation efforts and reuse to operational changes such as modifying the timing and amount of reservoir releases or storage levels and to structural changes such as increasing dike levels or adding storage.

> *The Utility developed initial adaptation strategies and evaluated their effectiveness in mitigating potential climate change impacts. These initial strategies were "no regrets" strategies that were low to no cost and easily implementable and that resulted in mitigation of potential impacts in all but the worst case emissions scenario. – telephone interview, May 15, 2009*

Similar to other water managers interviewed, the climate change impacts study reinforced the importance of conservation as an essential component of the Utility's climate change strategy.

Interestingly, among the PNW states only Washington has extensive planning requirements for local water systems. These requirements include planning for growth, water supply reliability, and conservation. The water supply reliability requirements are quite extensive mandating systems examine reliability in terms of quantity and quality and have a plan for water shortages (WADOH 1997). The planning also includes consideration for water rights in the event forecasts and anticipated shortage conditions necessitate acquiring additional water rights. These plans are reviewed by regional planning authorities as well as the state, a level of integration and communication that is rare for state mandated local water resource planning. However, planning requirements do not expressly require consideration of climate change impacts on water supply reliability. Unlike Washington, Oregon does not require local water systems to incorporate climate variability in water planning and like Washington, Oregon does not require the incorporation of potential climate change impacts into water supply planning (telephone interview, June 16, 2009; telephone interview, June 30, 2009). Municipal water supplies are required to have master plans that typically detail the source of supply and infrastructure for treatment and distribution of water and planning sufficient for growth. Emergency management under shortage conditions and conservation are required under Water Management Conservation Plans (WMCP) for municipal water suppliers to fulfill new water right permit conditions but again climate change is not included in WMCP requirements.[1] Idaho requires water systems to plan for future growth but does not require planning for climate variability or climate change impacts (pg. 42)[2].

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[1] Oregon Water Resources Department. (2002). Municipal Water Management and Conservation Plan Outline. OAR 690-086-0140 available at: http://www1.wrd.state.or.us/pdfs/muni_plan_matrix.pdf

[2] Idaho rules for public water systems Chapter 58.01.08 available at: http://adm.idaho.gov/adminrules/rules/idapa58/0108.pdf

6.2.1.3 *Generalized Mechanisms of Disturbance and Response for Local PNW Utilities*

The effect of perturbations on five water systems and the organizational responses to these perturbations were outlined in the previous section. Now, two conceptual maps are presented showing the generalized mechanisms of perturbation and response for PNW water systems. First, in Figure 6.1 generalized local water management is illustrated with perturbations summarized on the left and responses summarized on the right. The water managers' function within the organization is summarized in the middle box. The middle box also includes the most important drivers of information use derived from the analysis described in detail in chapter 5.

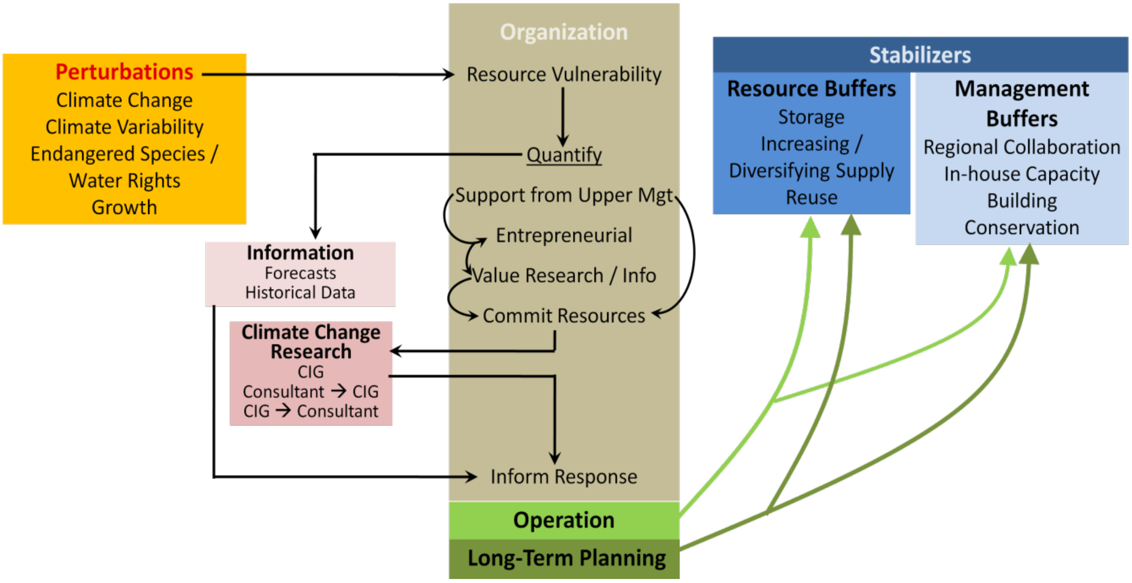

Figure 6.1 Mechanisms of perturbation and response for water managers in the PNW.

The drivers of information use shown in the middle box help to explain how water managers internalize and react to the external threats to the resource. The perception of a water resource threat is the activating step in the absence of other external driving forces. This activating step leads to quantification of the perceived threat. If information use is focused on forecasts and historical data, the quantification is fairly straightforward. Historical information is often held internally within organizations whereas forecasts can either be generated internally or obtained externally. Forecasts inform shorter term operational decisions such as reservoir operation, shown in the figure as a resource buffer, and short-term conservation measures, shown in the figure as a management buffer.

The use of climate change information is often more complex generally requiring support from upper management to enable the commitment of resources to invest in obtaining climate change impacts information. Climate change information is exclusively obtained through the RISA either directly or through a consultant. Once obtained, this information is often used in long-term planning to inform decisions such as diversifying water supplies, engaging in regional collaborations, or undertaking long-term, more comprehensive conservation efforts. The information may also lead to longer-term changes in operation (i.e., changing the way a reservoir is managed).

While Figure 6.1 suggests water managers' internalization of resource vulnerability triggers short- and long-term planning efforts and the use of climate information, there is some evidence to suggest external drivers may also play a role in the use of climate information for planning. For example, some water managers mentioned having progressive local leadership that fostered a city-wide culture of innovation. Others mentioned, willingly or unwillingly participating in regional planning efforts that incorporated climate information. Water rights negotiations are also opportunities for external pressure and influence on local water managers. And, for Washington State in particular, state water planning requirements may be partly responsible for fostering conditions wherein water managers routinely engage in resource reliability planning. These external influences on local PNW water managers are illustrated in Figure 6.2.

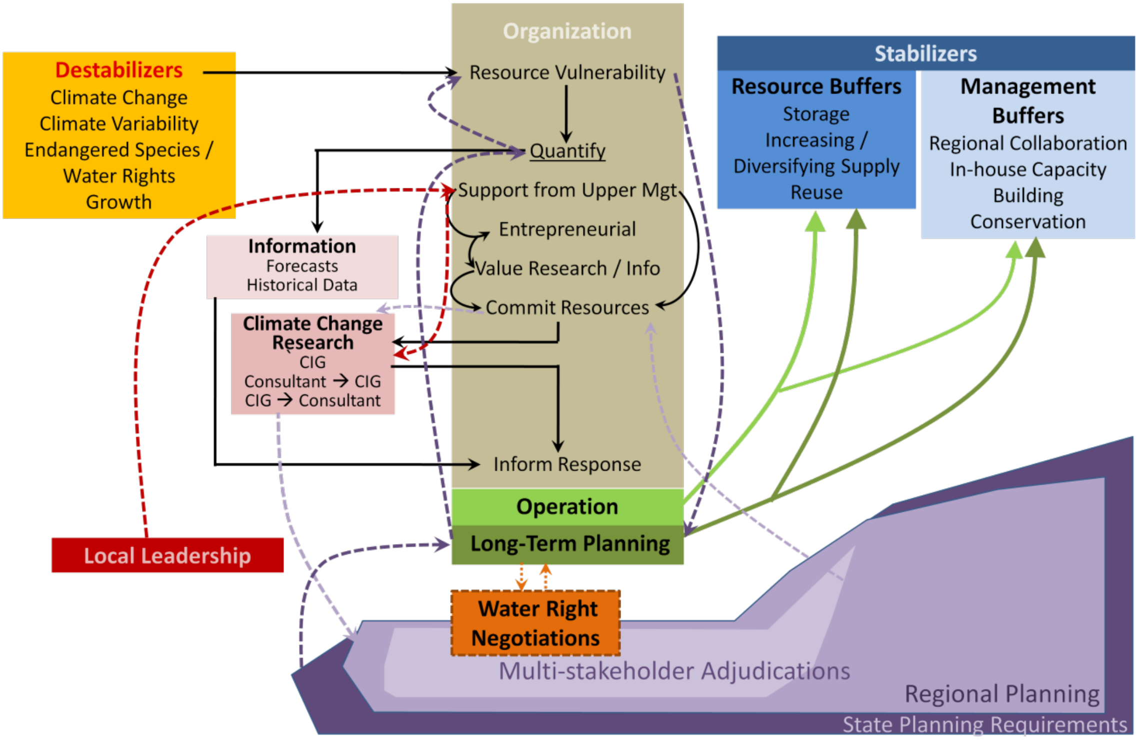

Figure 6.2 External influences on local water managers in the PNW.

While regional planning efforts and local leadership were mentioned by a number of PNW water managers as playing a role in information use and long-term planning, none of the water managers mentioned state level requirements for planning as motivating information use. In any case, the use of climate change research goes well beyond any state planning requirements. This suggests PNW water managers have an organizational culture that supports the use of this information (and climate information from other sources). Alternatively, water managers may be motivated to use climate information through their involvement with the RISA.

6.2.1.4 Outcomes and Resilience

The ways in which RISA information has informed policy and planning responses to buffer against perceived resource vulnerabilities was described in the previous section. Now, a single case is explored to examine how RISA information use in planning increases resilience of water management systems. The focal system serves less than 100,000 people. Consistent with the other four water systems this water system possesses the indicators of organizational resilience including a commitment to planning, information seeking, awareness of resource vulnerability, human, technical, and financial capacity, and a culture of collaboration. The perceived risk to water resources focuses on the potential of reduced water availability due to an adjustment of water rights based on negotiation of instream flows. Furthermore, the utility recognized that climate change may exacerbate this identified risk and that climate change posed a threat to their glacially dependent water supply and to overall water availability. This perceived risk to their water resources motivated the use of climate change information in water supply planning and in informing and forming the utility's position to negotiate water rights and instream flows. CIG's predicted temperature, precipitation, and precipitation timing changes were used in the water utility's hydrology model to determine climate change impacted streamflow scenarios. This information was then fed into the utility's hydraulic model. Together the output from those modeling efforts helped determine potential impacts on the utility's water supply diversion ability and reservoir capacity. The information has helped the utility plan for climate impacts on their water supply and has informed and formed their position at the negotiation table for water rights and in-stream flow issues. Remarkably, the utility does not need complete certainty or an exact number to use in planning for future water supplies. They prudently plan and hedge their bets with the current level of uncertainty.

The water manager's relationship with CIG paved the way for the use of climate change predictions for water supply planning and negotiating water rights. By incorporating climate change impacts into planning the water system builds resilience potential. Using potential climate change impacts to inform their negotiation position for water rights takes the information use a step further. The information enhances the utility's water supply reliability by enhancing the robustness of the utility's position in the negotiation and potential future water supply reliability.

The exploration of how local level water managers' use of climate information in response to threats to water resources to help build resilience potential masked a larger view of local level knowledge-action systems. The knowledge-action systems for local water management were much more developed in Washington State where RISA information helped four local water systems examine climate change impacts and determine local responses to those impacts. There were no local water systems using RISA information in Idaho and only one local water system using RISA information in Oregon. While seemingly small in number, the establishment of knowledge-action systems for even these few local water managers is important. The use of RISA climate information and the subsequent improvement in the water systems' resilience to climate impacts affects over three million people. However, while provision of information to these systems is important, there is clearly a difference in the expansiveness of the local level knowledge-action systems across the three states.

6.2.2 Regional and State Level Analysis

This difference in expansiveness of knowledge action systems extends to other levels of governance as well. The only county governments integrated into a knowledge-action system were located in Washington State. Boundary work facilitated the translation of science to action through examining the county regional water planning efforts. The County hired CIG to provide the technical modeling work to downscale the latest global climate model results from the Intergovernmental Panel on Climate Change to generate county specific information on likely climate change impacts. The involvement and leadership of CIG facilitated the communication, translation of scientific results, and mediation of varying and sometimes opposing views and ultimately, helped produce consensus statements on the likely effects of climate change (telephone interview, May 26, 200). Leadership of the county executive and the technical and scientific literacy of staff from the utilities and county departments also helped ensure the success of the regional planning effort (telephone interview, May 29, 2009). This example suggests effective knowledge-action systems depend not only on the knowledge producers (i.e., RISAs) but also on the capacity and leadership of the policy makers (i.e., knowledge users).

Results from the regional planning effort gave local water utilities more information about how climate impacts might affect the region as a whole and, in one case, brought climate change considerations into a local water utility that were not being considered before the regional water planning process. For the county, information from the regional planning process was used to support the decision to move forward with efforts to increase the availability of reclaimed water to supplement freshwater supplies. In Washington, the county is responsible for wastewater management but most of this water is discharged to surface water bodies instead of being reused. The potential impacts of climate change and the stress from drought and growth means county planners can justify capital outlays necessary to treat wastewater for reuse by anticipating future demand for reclaimed water. Reclaimed water can be used for non-potable irrigation relieving pressures on potable water supplies. The county also used the climate change information to support the creation of a Flood Control Zone District to generate funds to pay for improvements to the levee system to withstand increased climatic variability and potential sea level rise (telephone interview, May 29, 2009). These and other actions were expressly designed to build resiliency (telephone interview, May 29, 2009).

Besides counties and local governments, CIG has also developed relationships with all three PNW state water resource management agencies to help translate science into state level policymaking. Here too variation in the implementation of the knowledge-action systems across states was observed. This variation arises due to differences in the context within which these knowledge-action systems develop. Next, the challenges posed by climate variability and change for each state are discussed along with the development of knowledge-action systems between CIG and state water management agencies.

6.2.2.1 Idaho State Agencies

CIG began interacting with the Idaho Department of Water Resources (IDWR) because the Director of the IDWR determined that it would be appropriate both for the Water Board and the Department of Water Resources to take advantage of CIG's expertise and any potential opportunities for cooperation (telephone interview, June 8, 2009). IDWR engaged CIG to provide technical expertise and assistance in understanding the dynamics of climate change and how it might affect Idaho. The incorporation of forecasts in decisions made by IDWR with regard to managing reservoir storage projects resulted from IDWR's interaction with CIG (telephone interview, June 16, 2009). The use of forecasts increases the resiliency of existing storage systems as it enables incorporation of future climatic conditions into operational decision making.

CIG has also interacted with the Idaho Water Resources Board (IWRB), the state planning and water policy making authority. The IWRB is looking at both climate variability and climate change impacts through the State Water Plan and the Comprehensive Basin Planning process. The existing State Water Plan (1996 Plan), a generalized water resource management policy and planning document, recognizes that climate variability should be included in planning and management and, surprisingly, addresses climate change to a limited extent (telephone interview, June 8, 2009; IWRB 1996). Specifically the Plan states:

> *"…climate variability should be expected and planned for by the public and its agencies. Possible consequences of regional climate change are important to recognize. …Even though uncertainties are considerable, we should not wait to put in place policies and procedures that could provide for flexibility and make use of new understanding as it develops." – IWRB 1996*

A review of the existing State Water Plan began in 2007. The latest draft is markedly different than the 1996 Plan with respect to addressing climate change. This reflects, in part, the IWRB's improved understanding of the potential impacts of climate variability and change gained through interaction with CIG (telephone interview, June 16, 200). The latest 2009 draft recognizes the uncertainties in climate change prediction but emphasizes the need to identify risks and build resiliency:

> *"Climate change resilience and preparedness goals should be guiding principles for Idaho water resource management."- IWRB 2009*

Even though the above language appears clear, later in the section entitled "Climate Variability" the language is more ambivalent (IWRB 2009). For example, there seems to be some hedging in the language of climate stresses attribution:

> *"High priority should be given to identifying and implementing actions designed to address water system stresses brought about by climate*." - IWRB 2009

This hedging of language is likely due to the controversial nature of climate change issues in the state (telephone interview, June 8, 2009). The term "climate variability" is expressly chosen because it is does not generate immediate resistance and controversy in the way the term "climate change" does among some politically important groups (telephone interview, June 16, 2009).

While climate change is controversial and this controversy is reflected in the draft 2009 State Water Plan, the Legislature did explicitly incorporate climate change activities into the recently authorized $20 million, 10-year, Comprehensive Aquifer Planning and Management (CAMP) effort (telephone interview, June 8, 2009). IDWR's real focus for climate change activities is not in the State Water Plan but in specific, CAMP basins. The planning process includes specific tasks to assess how future climate changes will impact water availability and operation at the basin scale in ten basins that exhibited areas of potential conflict or areas that needed to incorporate planning for future water needs over the next 50-years (telephone interview, June 16, 2009). Eight of the ten CAMP basins are in Southern Idaho where the climate is desert-like and where potential conflict and the need for future water supplies is the greatest (telephone interview, June 16, 2009). Incorporating climate change into the planning process may eventually entail changing operational plans for either earlier or later runoff or perhaps the creation of additional storage sites because of the change in runoff (telephone interview, June 16, 2009). Negotiations for the inclusion of climate change in the CAMP effort were not without challenges. In the end most lawmakers conceded it made sense to look at the potential impacts of climate change given the millions of dollars being invested in water infrastructure and planning:

> *The conversation had to be steered away from the causes of climate change to focus instead on the importance of understanding the potential impacts given the amount of money being invested [and the long term nature of those investments]. - telephone interview, June 8, 2009*

These CAMP plans are similar to Comprehensive Basin Plans but they are more narrowly focused because the intent is to look at meeting future water needs and avoiding conflicts (telephone interview, June 16, 2009). IDWR is looking at all of the water resources including both surface and groundwater resources within each basin to identify what water is available, what the future demand may be, and how those demands will be met. The IDWR is not independently undertaking climate change activities other than those associated with CAMP.

6.2.2.2 Oregon State Agencies

Oregon has been slow to respond to the potential impacts of climate change. Interviewees suggested part of the reason was due to the State Climatologist who was reticent to put too much trust in anthropogenic climate change (telephone interview, June 16, 2009). The Oregon Water Resources Department (OWRD) was also slow to incorporate climate change information. Eventually, the Water Resources Commission, the appointed body that oversees OWRD policy, pressured OWRD to better integrate climate change impacts information. Unfortunately, progress incorporating climate change information was stymied because OWRD did not know how to integrate climate change into policy and planning. Over time and through interaction with CIG, the OWRD achieved greater understanding and CIG's modeling and technical capabilities improved and more practical applications emerged, the OWRD began to translate the information CIG was generating into analyses of how climate change might be considered in water resources management (telephone interview, June 16, 2009).

> *"That was the bridge; making it applicable to what OWRD does." – telephone interview, June 16, 2009*

Now, climate change efforts are being driven more from the agency level because they have a greater understanding of how to apply the information within existing programs. For example, the OWRD recently funded a small project to help understand which areas were the most vulnerable to changes in snowpack (telephone interview, June 16, 2009). Results from that and other studies on the potential impact of climate change on snowpack were important drivers for funding the 2007 Oregon Water Supply and Conservation Initiative (WSCI) which includes understanding how conservation and storage alternatives might address anticipated losses in natural storage from climate change (telephone interview, June 16, 2009). In addition, the OWRD is now helping to fund a larger effort to examine regional climate change at a finer spatial scale for the Columbia River watershed (Ecology 2007).

Interactions with CIG have increased OWRD's interest in better understanding the potential impacts of climate change on Oregon water resources. However, the state is behind in terms of altering management practices or policies to build resiliency. And, unfortunately, projected climate change impacts including a predicted decline of 35-45 percent of snowpack by mid-century may have profound impacts on Oregon water resources (Boggess & Woods 2000; Hamlet & Lettenmaier 1999) because more than 50 percent of the state depends on a water supply fed by mid-elevation snowpack (Boggess & Woods 2000). If climate change decreases the amount of water available, the state may face serious water management challenges given much of the surface water and a large amount of the groundwater in the state is fully allocated or over-allocated in during the low flow periods of late summer and early fall (Boggess & Woods 2000; telephone interview, June 16, 2009).

6.2.2.3 Washington State Agencies

In Washington, the Department of Ecology (WADE) has water resource planning and policy making authority and also provides funds for water systems. Climate change is one of the Department's chief issues. That prioritization of interest and internal leadership motivated the creation of a Climate Change Team that reports to the Director and an Office of Climate Policy that is housed in the Executive Office. Beyond the Department, there is also interest in climate change at the office of the governor.

CIG and key staff at WADE have formed a good working relationship over time. However, there are still challenges in extending relationships between CIG scientists and staff within the Department and state government. One of the challenges CIG faces when working with Washington State water management and policy making departments is they are perceived as being too connected to the science (telephone interview, May 22, 2009). Washington Department of Ecology (WADE) staff performs additional boundary work to further translate science into a form that is useful for policymakers. The upstream interaction with CIG and the downstream internal translation of the science built confidence in the process and in scientific understanding over time. This eventually led to the state commissioning a state assessment of climate change impacts which was completed in 2009 (personal interview, February 13, 2009). The state is now better informed to begin addressing potential impacts of climate change but thus far, policy has been slow to change. For example, all the money the State gives out through its grant programs to local water systems is not conditioned on consideration of potential reductions in water supplies due to climate change (telephone interview, May 22, 2009). There is no explicit mention of climate change in any of the planning exercises. Furthermore, any changes to the policy will likely meet with resistance since water managers are barely keeping up with existing regulations and maintenance needs (telephone interview, May 22, 2009). Another challenge moving forward is how to deal with over-allocated water resources in the face of potentially diminishing supplies as the water resources in the state are already over allocated.

6.2.2.4 Pacific Northwest State Information Use Summary

A few insights can be drawn from CIG's interaction with state water resources agencies that promoted the use of climate science in policy and planning at the state level. First, the knowledge-action system is facilitated by relationship building between the state agency staff and CIG. For example, the RISA scientist-stakeholder relationship contributed to climate information use in Idaho by the IWRB in the State Water Plan and by the IDWR to inform localized operational decision making. Second, the IDWR staff used RISA information to help influence state representatives to include climate change activities in a new state basin planning effort. Without IDWR staff willingness to champion climate change issues at the state legislature and influence policy it is unlikely climate change information would be integrated into water resource planning by the IDWR. Similar internalized boundary work was observed in Washington. Staff at the Washington Department of Ecology translated CIG climate science and moved the science into the policy-making sphere, work that contributed to the decision to contract with CIG to undertake a statewide climate change impacts assessment and investigation of adaptation options. The decision to undertake a statewide climate change assessment was also facilitated by the governor's interest in climate change. Elected officials' interest in or concern for potential climate change impacts on water resources may also facilitate use of climate information in policy and planning. Elected officials on the Oregon the Oregon Water Resources Commission also exerted influence in this case on the Oregon Water Resources Department to consider the impacts of climate change on water resources. Fourth, state climatologists may impede or advance state-wide responses to climate change. For example, in Oregon, the prior state climatologist worked to diminish state-wide consideration of climate change impacts slowing state responses to potential climate change impacts. On the other hand, the Washington state climatologist helped advance consideration of climate change impacts in the state. Interestingly, the Washington state climatologist was, until recently, affiliated with CIG.

6.3 SW Water Resource Management & Information Use

6.3.1 Local Level Analysis

I interviewed seven water managers from SW water utilities that varied in the amount of water delivered and number of people or systems served. The smallest utility served fewer than 20,000 people while the largest utility interviewed served over one million people. All seven utilities were governed by elected bodies consisting of either a mayor and city council or an elected Board. As with the PNW stakeholders, SW water managers oversaw systems that varied in size and management structure. Yet here too, similarities emerged. The commonalities are again categorized according to the analytical framework: perturbations, management responses enacted to buffer against known or anticipated perturbations, and information used to quantify the risk and inform the management response.

6.3.1.1 Perturbations

Southwest CWS managers are sensitive to climatic conditions and to other issues that might lead to reductions in their water supplies (e.g., endangered species protections, increased groundwater withdrawals that might affect their surface water allocations, etc.) including climate variability and change. Both Arizona and New Mexico have experienced a number of severe droughts over the last century. Severe to extreme drought (i.e., a -3.0 or less on the Palmer Drought Severity Index) has affected some portion of New Mexico 55 percent of the time during the last hundred years (Liles 2003). Of the many droughts experienced over the last century the 1950s drought was considered New Mexico's worst. However, New Mexicans have begun to reconsider what is normal given tree ring reconstructions suggest the 1950s drought may be closer to the normal climate for the state. In fact, the last decade of drought is now considered the drought of record (D'Antonio 2009). Like New Mexico, Arizona has experienced a number of major droughts over the last one hundred years but, there too, paleoclimate data indicate these more recent droughts may pale in comparison to deeper and longer droughts that have occurred over the past 1,000 years. A significant concern for Arizona is the changing snowmelt regimes for the Colorado River because snowmelt contributes more than 70 percent of the annual runoff to the river and the river provides some 40 percent of the water supply (Garfin *et al.* 2006). Another concern is the possible shift in the onset of the North American monsoon to later in the summer (Anderson *et al.* 2005) leading to declines in already low summer season streamflows (Anderson *et al.* 2006) when higher temperatures increase demand for both instream and out-of-stream uses. New Mexico water managers are also concerned about the potential impacts of climate change on the Colorado River since large urban areas are now tapping into New Mexico's Colorado River allocation through the San Juan-Chama Project. Adding to these challenges is the fact that many surface water sources are fully- or over-allocated.

Southwest water resources are challenged not only by the arid climate and climate change but also by population growth. Water managers are sensitive to needing water for future growth and to increasing competition for water supplies. In Arizona per capita water use has declined since the mid-1980s but, population growth has outstripped any accrued savings from demand management (Holway 2006). Between 1990 and 2000, Arizona's population increased statewide by 40 percent and projections indicate Arizona's population will continue to increase markedly over the next 20-30 years (U.S. Census 2005) to more than double by 2050 (Holway 2006). Like Arizona, New Mexico's water resources are stressed by population growth. Between 1990 and 2000, New Mexico's population increased statewide by 20 percent and projections indicate New Mexico's population will continue to increase markedly over the next 20-30 years leading to an overall population increase of 15% by 2030 (U.S. Census 2005).

6.3.1.2 Stabilizers and Information Use

An aspect of the organizational culture shared by all seven CWS water managers interviewed is the goal of providing a reliable water supply even during drought. For SW water managers, the drought perturbation was internalized as a threat to water managers' ability to provide a reliable water supply. The goal of providing a reliable water supply initiated responses aimed at mitigating the threat through infrastructure development (telephone interview, March, 27, 2009) or engaging in water resource planning and diversification of water supplies (telephone interview, July 2, 2009). Ensuring a reliable water supply was also invoked in response to other perturbations: growth and water for the environment (i.e., instream flows).

Because drought is so prevalent in the SW, many of the water managers interviewed expressed this sensitivity as causing them to routinize drought. In other words, these water managers consider drought conditions to be normal rather than aberrant and so routinely plan for scarcity. Some interviewees normalized scarcity years ago and have used that approach to guide management and decision making for decades while others have adopted this approach fairly recently. Those who have made the switch more recently point to increasing population growth, over-allocated supplies, and a prolonged drought as reasons prompting the change in approach. These same pressures also weigh on those who were ahead of the curve bringing reliability of future supplies into a sharper focus.

Though water managers normalize scarcity, they remain sensitive to climatic conditions. As such, water managers seek information about past, present, and future climatic conditions to help inform decision making to ensure the availability of adequate water supplies even during drought. While ensuring a reliable water supply did not in and of itself drive information use, coupling a reliable supply with climate sensitivity supported decision making behavior that included the use of climate information such as forecasts, climate change projections, and to a much larger degree, tree ring reconstructions. The climate information used by SW water managers was obtained through a variety of sources including CLIMAS, the National Weather Service, and other RISAs. One particularly resourceful Southwest water manager interviewed for this research used a variety of forecasts including drought projections and El Niño reports to help understand what was happening in the short-term and to look at potential variability in newly developed water supplies anticipated to come online in the near future. Another interviewee lamented that climate change impacts information was not readily available for water managers in the state. Without a local resource available, water managers sometimes look well beyond their borders for useful information. For example, one interviewee used Western Water Assessment reports to inform anticipated reductions in surface water supplies due to climate change. They then used this potential reduction as an input parameter to their system model to gauge future water availability under climate change. This interest in climate change information was echoed by five out of seven SW stakeholders.

Tree ring reconstructions enable water managers to look beyond the instrumental record to help place events that occur within the 100-year instrumental record in perspective. This perspective helps water managers understand if 20th century extreme low flow events are unusual or are more or less severe than low flow events that might have occurred in the much longer tree ring record. Five out of seven SW water managers interviewed use tree ring reconstructions to inform decision making. Interestingly, water managers did not universally use this information about past climatic variability in the same way. Some water managers used tree ring reconstructions to inform short-term planning such as year-to-year water availability or shorter-term water leasing decisions. Others use tree ring reconstructions to inform decisions around infrastructure sizing and to inform long-term planning or as a proxy for climate change:

> *Tree ring analysis indicated the worst drought occurred during the 1200-1300s. We used this information to help size our new well field to ensure water demands would be met even in the historically worst conditions. – telephone interview, April, 10, 2009*

> *An analysis of tree ring reconstructions for our watershed indicates the most severe drought lasted 30-years. We now use that 30-year drought for planning purposes. – telephone interview, March 12, 2009*

> *Tree ring and the instrumental record are being used to help understand what climate change impacts might look like in the watershed for planning purposes. Until there is a better understanding of some of the climate change models and until there is downscaled information available for the watershed, tree ring data are used to help inform potential climate change scenarios. – telephone interview, March 27, 2009*

Water managers recognize the value of climate information for decision making to help achieve the ultimate goal of ensuring a reliable water supply. To that end, SW water managers are increasingly willing to fund climate research singly or in partnership with others.

Water organizations are working on multiple fronts to address climate variability and change and to ensure a reliable water supply for the foreseeable future. For example, most water managers interviewed detailed extensive water conservation programs and incentives to reduce water demand. Rather than simply focusing on increasing supplies, water managers actively sought to manage demand as well to take pressure off water supplies. Conservation programs included incentives for water saving appliances and fixtures, tying new development to water supply availability, rainwater harvesting, and gray water initiatives.

Arizona has a history of planning in Active Management Areas (AMAs). Recently the state has introduced stricter regulation for local level planning within AMAs that includes planning for drought, conservation, and water supply and requirements for water supply reporting outside of AMAs. The goal within AMAs is to ensure there are plans for shortage conditions and to ensure water is used efficiently. Requirements for local level water availability and use information reporting outside of AMAs is new for Arizona as is the incorporation of that localized information into state and regional water planning. There are no specific planning requirements for local water systems in New Mexico though systems are "encouraged to have drought conservation plans and to do emergency planning" (telephone interview, June 17, 2009). Local water systems are also encouraged to enact water conservation policies (NMED 2008). Neither state requires planning for climate change impacts at the local level.

6.3.1.3 Generalized Mechanisms of Disturbance and Response for Local SW Utilities

A similar approach to that undertaken for the PNW is used to conceptualize mechanisms of perturbation and response for SW water systems. In Figure 6.3, perturbations are again summarized on the left in the figure, responses on the right, and the water managers' organization is represented by the middle box. As before, the middle box includes the most important drivers of information use derived from the earlier analysis in chapter 5, filtered to reflect the predispositions of SW water managers.

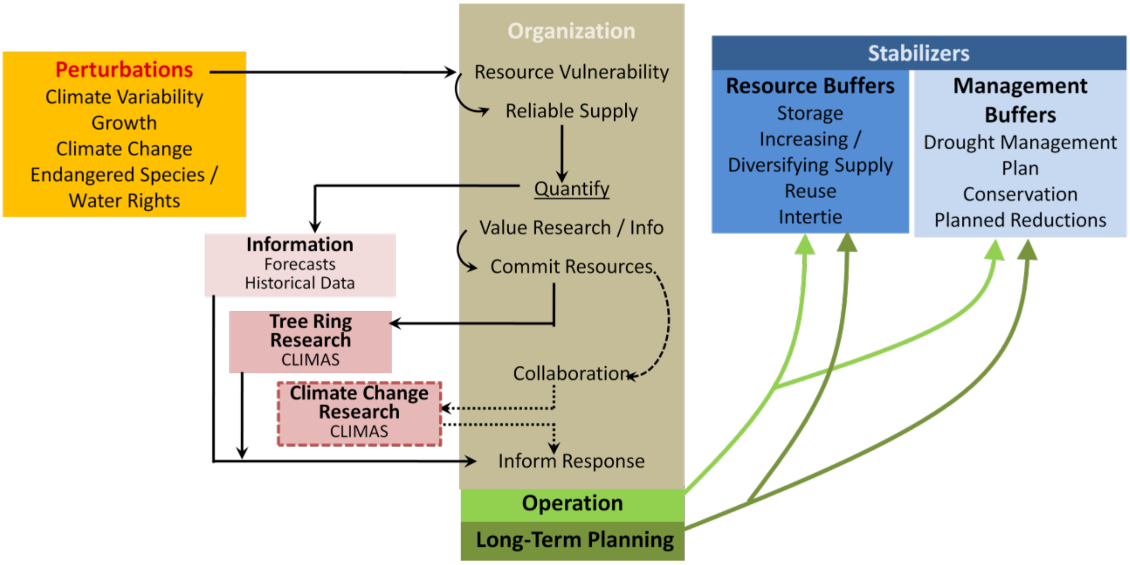

Figure 6.3 Mechanisms of perturbation and response for local water managers in the SW.

The drivers of information use shown in the middle box help to explain how water managers internalize and react to the external threats to the resource. The perception of a water resource threat is again the activating step in the absence of other external driving forces. However, for SW water managers the commitment to a reliable water supply is a constant motivator mostly because SW water managers are almost always managing in a drought or under water stress. Perceived resource vulnerability coupled with a commitment to a reliable water supply motivates water managers to quantify the resource threat. The use of forecasts and historical data is again straightforward and routinized. Forecasts inform shorter term operational decisions such as reservoir operation, shown in the figure as a resource buffer, and shorter term conservation measures, shown in the figure as a management buffer. Forecasts also inform supply switching, such as switching between surface and groundwater sources, or short-term water leasing decisions both of which are examples included as resource buffers.

The use of tree ring reconstructions is also fairly straightforward. It is possible the use of tree ring reconstructions was more complex when the information was first being integrated into decision making since there would have been a process of first justifying the expenditure of resources to obtain the information and then a process of integrating that new information into the response framework. At this point, the process of using this information is simpler. Water managers value this information and use the reconstructions for a variety of purposes including as a proxy for climate change. Tree ring data are exclusively obtained through CLIMAS. The use of downscaled climate change information is not as prevalent among local water managers in the SW as it is in the PNW. However, there is interest in collaboratively funding climate change research that would provide more specific local climate change impacts information but that research is not yet underway. As such, climate change research is depicted using dashed lines to indicate future information use potential.

Figure 6.3 suggests water managers' internalization of resource vulnerability and commitment to a reliable water supply trigger short- and long-term planning efforts and the use of climate information. Indeed, this is generally the situation. However, it is possible AMA planning requirements play a role in forecast information use and in efforts to undertake long-term planning for some water managers. That said, at least two utilities have been planning independently of any state requirements and the use of tree ring reconstructions goes well beyond state requirements. This suggests that, like PNW water managers, SW water utilities are self-motivated to use this information or are motivated through their involvement with the RISA. The other external influence to note is local leadership. Local boards or councils generally must approve any substantial resource expenditures for research. Even so, local boards and councils do not generally constrain climate information use, unless overall budget limitations play a role. In fact, members of local boards and councils may at times exert pressure on water managers to consider climate change impacts which may lead to the use of climate change information. Lastly, limited evidence indicates local councils may intervene to require long-term planning that was not initially undertaken by the utility. Like the PNW water manages, none of the water managers cited state level requirements for planning as motivating information use. The external influences on SW water managers' information use is summarized in Figure 6.4.

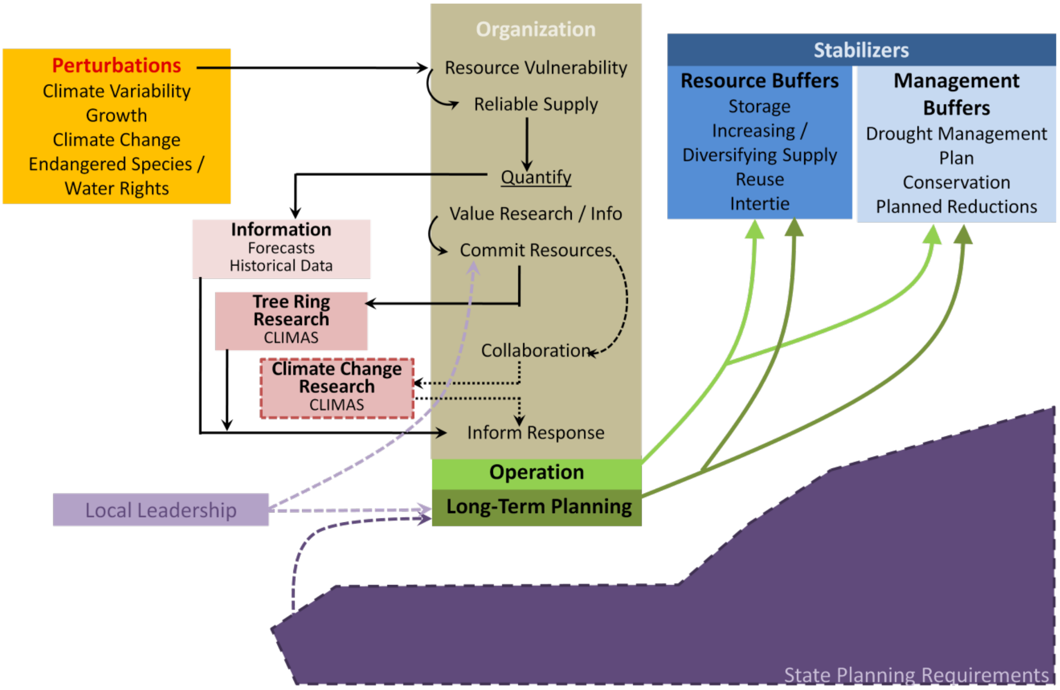

Figure 6.4 External influences on local water managers in the SW.

6.3.1.4 Outcomes and Resilience

From the previous section it is clear local water managers have used RISA information to inform policy and planning responses to buffer against perceived resource vulnerabilities in the SW. Now, a single case is explored as an example of how RISA information use in planning may increase resilience potential of a water management system. The focus is a system that serves less than 200,000 people. Consistent with the other six systems interviewed, this system possesses the indicators of organizational resilience including: a commitment to planning, information seeking, perception of resource vulnerability, human, technical, and financial capacity, and a culture of collaboration. The utility is keen to maintain a reliable water supply that accommodates growth without the need for water restrictions for the next hundred years. The perceived risk to water resources focuses on drought that impacts not only water available for purchase but also water for recharge facilities and supply switching. The utility does not incorporate climate change projections information due to discomfort with global climate models that do not include regionally specific climatic processes and influences. However, the utility uses tree ring reconstructions to inform year to year water purchases and long-term water supply planning. Interestingly, the utility also used tree ring reconstructions to inform and support the need for infrastructure construction. They used the worst drought indicated in tree ring reconstructions to help size an aquifer storage and recovery facility to ensure a reliable water supply even during the worst historical drought.

The water manager's relationship with CLIMAS scientists paved the way for the use of tree ring reconstructions for water supply planning, informing year-to-year water purchases, and well field construction. By incorporating tree ring information into planning the water system builds resilience potential. Resilience potential is also built through the use of tree ring data to inform well field sizing. Without tree ring data, it is likely the utility would principally rely on the historical record and/or a simple factor of safety to bound potential climate variability and change putting the utility at greater risk. The data provide a much longer historical and proxy record of climate variability and change to help quantify risk and buffer against that risk, which results in improved resilience potential.

Like the PNW, analysis of information use at the local level masked the unevenness in development of knowledge action systems between CLIMAS and local water managers. Local knowledge-action systems were much more extensive in Arizona where RISA information helped six local water systems examine climate perturbations and determine local responses to those impacts compared to only two local water systems using RISA information in New Mexico. However, as with the PNW, while the total number of systems is low, nonetheless, the action of these individual systems affects some 2.6 million people. Therefore, their use of RISA information to improve water system resilience is significant for the region.

6.3.2 State and Regional Level Analysis

In the Southwest, counties do not have much in the way of authority over water resources planning. So, while one Arizona County was a RISA client, their use of information was limited because of their limited authority. As a result, the effectiveness of the knowledge-action system also suffered. No counties worked with CLIMAS in New Mexico. The next two subsections focus on the interaction between CLIMAS and state level water resource managers in both New Mexico and Arizona. This focus provides a means to explore the development of knowledge-action systems at the state level. Examining interactions and knowledge use enables a better understanding of what makes these knowledge-systems effective for building resilience to climate variability and change in the SW.

6.3.2.1 New Mexico State Agencies

The potential impacts of climate change present significant potential challenges for New Mexico water resources management. CLIMAS scientists have been working alongside New Mexican scientists, water experts and advisors to raise the level of awareness and understanding of climate change impacts and to help the Governor's Blue Ribbon Water Task Force and others begin thinking about how to incorporate climate change impacts and adaptation needs into water projects (telephone interview, March 24, 2009). The Governor requested a study and report on Climate Change Impacts for the state and the potential impacts of climate change on New Mexico water resources specifically to better understand the potential impacts of climate change (E.O. 05-033). CLIMAS scientists were an important participant and contributor to the latter. Research undergirding the report indicates significantly diminished snowpack is projected not just for the Colorado River Basin but also for important New Mexico rivers by the end of the Century (Garfin *et al.* 2006). Besides the Colorado River, New Mexico relies on the Rio Grande where 50-75% of annual flow is generated by snowmelt (Rango 2006). The concern is that Rio Grande flows might be reduced if snowpack diminishes as projected, mirroring anticipated reductions in flows for the Colorado River (Gutzler 2006). These impacts have important potential implications for water supply and management (Leavesley 1994; Stewart *et al.* 2005, Rango *et al.* 2003). For example, having more runoff in the winter months rather than in the warmer summer months may increase competition for water in the Rio Grande. Climate change projections also point to a more vigorous and lengthy monsoon season. Unfortunately, New Mexico infrastructure is built to store snow melt in reservoirs not to capture monsoon rains (telephone interview, April 23, 2009).

Consideration of potential climate change impacts is not required in planning at the regional or state level. This reflects not only the nascent state of understanding of climate change impacts for the state but also the stance of the Office of the State Engineer (NMOSE) that “did not believe climate change was anything to worry about” (telephone interview, March 24, 2009). Part of the complacency around climate change at the State Engineer’s Office and at the state legislature may be driven by a surprisingly low level of interest in water in general by the public and elected officials: “…water problems in the West don’t have a high priority in New Mexico’s popular consciousness” (Price 2009). Complacency may also be driven by lack of confidence in climate change modeling (telephone interview, April 6, 2009). There is evidence that attitudes are beginning to shift in spite of the impediments to action on climate change. Recently, the State Engineer came out strongly in support of the science of climate change and of the need to address climate change impacts:

> *“Evidence is clear.” – John D’Antonio (2009)*

This change of heart was likely a result of increasing awareness of the vulnerability of New Mexico’s water resources to climate variability, in particular, and possibly climate change considered in conjunction with the many other significant water management challenges in the state. The shift was also very likely a result of actions taken by the Executive that: pushed the state from drought response towards drought preparation; raised the level of awareness of climate change; and, positioned the state to begin first to mitigate climate change and most recently to move towards resiliency and adaptation. CLIMAS, as mentioned previously, played an important role alongside scientists from New Mexico in conveying climate variability and change information. In 2009, Governor Bill Richardson signed Executive Order (E.O.) 2009-047 that marks the first steps toward adaptation in the water sector. E.O. 2009-047 includes clear and compelling language directing the Office of the State Engineer to “recommend resilience strategies to address predicted temperature increases" and "assist the State and its water users to meet the anticipated changes in water resources due to climate change impacts":

> *"In consultation with the Office of the State Engineer, convene a Resilience Advisory Group to develop a State Climate Change Resilience Plan. The Advisory Group shall present a report to the Governor's Office with recommendations for climate change resilience strategies to address predicted temperature increases from global warming. The Advisory Group shall finalize no later than December 1, 2010, its report with findings and recommendations, including recommendations to assist the State and its water users to meet the anticipated changes in water resources due to climate change impacts." – E.O. 2009-047*

The Governor has also taken other steps to move the state forward towards better integrated management of water resources. For example, in 2007 the Governor created a Water Cabinet that is presently working to expand the scope and reach of the State Water Plan to bring other agencies besides the State Engineer to the planning process (Hume 2007; NMOG 2007). The new commitment to building climate change resilience and more integrated water management are reflected in the latest update to the State Water Plan. For example, the update recognizes that "public awareness and concern over global climate change has grown" and that the plan must "address the impact of climate change on water availability, water management, and other state resources" (NMOSE 2008). Furthermore, the update stresses the importance of coordinating with other state agencies and outside entities and better linking the state plan and regional water plans (NMOSE 2008). This progress report and proposed update to the State Water Plan are vastly different than the language and approach in the first State Water Plan published in 2003 and the 2006 progress report (NMOSE 2003; NMOSE 2006).

New Mexico also engages in state level drought planning organized through the Executive Office. Drought planning is important because it affects water availability for farmers and municipalities, the state's largest users, and New Mexico's ability to meet interstate compact delivery obligations. Drought planning in the 1990s and early 2000s was more reactive than proactive in response to drought conditions. As modest rains fell, the emergency subsided and so did the urgency of drought planning:

> *Earlier in this decade when the State was in a drought, the Governor convened task forces and there was a Drinking Water Task Force Subcommittee and things were pretty-well structured. And, then it started raining again, and they just closed up shop. – telephone interview, June 17, 2009*

The emphasis on reactive drought planning began to shift after Governor Richardson was elected to office. In 2003 Governor Richardson issued an Executive Order (E.O. 2003-019) declaring a state of emergency due to drought and establishing a new, New Mexico Drought Task Force (NMDTF 2006). This declaration resulted in a sustained effort directed at drought preparedness and planning from 2002-2006. CLIMAS scientists were important contributors to the NMDTF (telephone interview, March 24, 2009). While the effort towards drought preparedness was an advancement over the normal drought response cycle (Watkins 2003), there has not been an update to the drought plan since 2006.

6.3.2.2 Arizona State Agencies

CLIMAS scientists have worked with state level Active Management Area (AMA) water managers for a number a years. Recently, CLIMAS developed tree ring reconstructions to provide a longer term view of climate variability for one AMA (telephone interview, April 13, 2009). The analysis indicated recent droughts are not unique and that droughts in the region can approach forty or fifty years in length (telephone interview, April 13, 2009). More importantly, the study changed the way AMA water managers view drought:

> *This study has made folks reconsider what are dry and wet years for the region and what might be normal for the region. It's possible the present drought is closer to normal while the shorter droughts and rainy periods that have been common over the past few decades were more abnormal. – telephone interview, April 13, 2009*

Unfortunately, budget constraints have made it difficult to fully develop a climate change impacts model for the AMAs. While the Arizona Department of Water Resources (ADWR) stays abreast of published reports and other climate change research, they do not have specific, local climate change impacts information developed for the AMAs (telephone interview, April 13, 2009).

The impacts of the recent drought from 1998-2004 focused attention on developing a state drought plan to limit the most severe impacts (Jacobs & Stitzer 2006). In response, Arizona's Governor, Janet Napolitano, established the first Drought Task Force (DTF) in 2003 when she signed Executive Order 2003-12 (AZDTF 2004b). Creation of the DTF shifted the responsibility of drought response at the state level from the Department of Emergency Management to the ADWR and shifted the emphasis from emergency response to drought planning. The shift in focus to planning resulted in significant effort to develop "an ongoing, sustainable planning process" (Jacobs *et al.* 2005). The motivation for the shift in focus from emergency response to planning and the creation of a high level DTF reflected the Governor's recognition that drought was "a very long-term problem" (Watkins 2003).

Executive Order 2003-12 also required the development of a Statewide Water Conservation Strategy (Strategy) and a Drought Preparedness Plan. The Strategy focuses on long-term improvements in efficiency of water use in the state while the Drought Preparedness Plan includes shorter-term conservation measures (AZGDTF 2004b). The Arizona Drought Preparedness Plan was completed in 2004 with a focus on drought planning in rural areas. CLIMAS scientists were integrated into the planning process and a stakeholder based approach was used to help "shape the research, monitoring, and communication processes of the [drought] plan" (Jacobs *et al.* 2005). CLIMAS scientists also participate as members of the Arizona Drought Task Force Monitoring Technical Committee (DTF MTC) formed in 2003 which advises the DTF on the science and strategies appropriate for drought monitoring in Arizona and provides monthly drought status reports to the ADWR (telephone interview, March 12, 2009). CLIMAS scientists have been integral to the development of novel local drought monitoring strategies as well as a comprehensive drought monitoring strategy for the state as a whole (telephone interview, March 12, 2009; telephone interview, December 9, 2008). The DTF MTC also provides technical advice to the Interagency Coordinating Group that advises the Governor on issues related to emergency declarations, funding, and improving the drought plan (telephone interview, March 12, 2009; Garfin 2006). The Statewide Water Conservation Strategy, completed in 2004, has not yet been fully implemented and most conservation efforts to date have occurred within AMAs with a few exceptions (i.e., Payson and Flagstaff) (Jacobs & Stitzer 2006).

The need to provide water in times of drought and to meet demands for growth have prompted increased attention to water planning in the state and to data and monitoring needs to support planning. However, early planning efforts were focused on AMAs in the 1980s due to passage of the 1980 Groundwater Management Act and statewide planning was delayed in the 1990s due to lack of funding. The first statewide water assessment (SWA), completed in 1994, provided a broad overview of water supply and demand to help identify water management issues across the state (Jacobs & Stitzer 2006). Except for the SWA, statewide planning did not advance significantly until 2002 when ADWR began focusing more on communities outside AMAs (telephone interview, March 12, 2009). Recently, ADWR developed a Water Atlas containing information for 51 groundwater basins, surface water hydrology, and effluent use in seven planning areas (ADWR 2010b). A report for each planning area includes an overview of the geography, hydrology, climate, environmental conditions, population and anticipated population growth to 2030, surface water, groundwater and effluent supply and demand, and water resource issues as well as information about land ownership and water quality (ADWR 2010b). The reports are detailed and informative and address some important data and monitoring needs to support planning. However, the data for individual water systems is somewhat opportunistic such that only data that has been reported to ADWR is included. Also, while the reports from the planning areas achieve the appearance of uniformity of coverage, there is a degree of unevenness between planning regions likely reflecting the constraint on information availability. Lastly, uncertainty resulting from unsettled Native

American water rights claims impedes state and regional water management planning (Smith & Colby 2006).

A closer examination of the six planning area documents reveals each contains climate information that describes not just historical precipitation and temperature trends but also long-term climatic data from tree ring reconstructions supplied by CLIMAS (ADWR 2009a). CLIMAS, cited as contributing authors for climate, also provide figures and information about the influence of ENSO cycles on precipitation patterns in the planning areas (ADWR 2009a). Climate change is mentioned but addressed only briefly. An example excerpted from one report from text in the "Environmental Conditions" section is as follows:

> *"Drought, wildfire and long-term climate change involving warmer temperatures with earlier Spring season and less snow cover could result in vegetative changes in the planning area with implications on runoff, infiltration and water supplies" (ADWR 2009a).*

One limitation of the planning documents is the sparseness of the information about tree ring reconstructions, ENSO, and climate change and the lack of tailoring of information for planning regions. The same information is repeated in all the planning region reports. Also, while the Governor has some interest in climate change, the ADWR does not have any particular programs directed at understanding climate change impacts on water resources (telephone interview, March 12, 2009). This lack of focus may also be reflected in the planning documents.

The regional planning reports include some information about current and impending water resource issues. However, much of the information is presented in list form without any discussion or analysis of real impacts. For example, water resource issues for the Central Highlands Planning Area include: (1) significant projected growth; (2) limited supplies to meet projected demands; (3) limited water resources to meet current demands; and (4) unresolved Indian water rights settlements. These lists that appear in most of the documents belie the critical nature of the issues in the planning areas. Only one planning area report quantified the criticality of the water resource issues, the Eastern Plateau Planning Area. In that report the potential for critical water shortages by mid-century and for existing critical shortages in some areas are identified:

> *"The North Central Arizona Water Supply Study (which includes Flagstaff and the western portion of the planning area and the Western Plateau Planning Area) concluded that by 2050 the region's groundwater pumping would not be sustainable and that unmet demands will be more than 7,000 acre-feet annually"(ADWR 2009).*
>
> *"Many Navajo communities also currently face critical water shortages. Water hauling is commonplace on the reservation… [and] at some locations outside of the reservation"(ADWR 2009a).*

Ultimately, a summary report describing the methodology used to create the Water Atlas and a Water Sustainability Evaluation will be authored by ADWR. It may be that the Water Sustainability Evaluation will take a closer, more critical eye to the existing water resources and anticipated demands. This more critical approach is needed to sufficiently advance water planning and build resilience in the state.

Arizona has limited mechanisms to address the connections between land use, population growth and water supply outside of AMAs. This lack of jurisdiction over water supply planning is particularly vexing outside of incorporated areas where counties play a larger role, yet have limited powers to enforce planning or water supply adequacy requirements compared to cities and towns (Jacobs & Stitzer 2006). For example, counties play a role in approving new development plans but, even if the water supply adequacy finding fails, development cannot be stopped and, in many cases development is encouraged by the County governments because growth is important for economic development (Davidson 2009).

One attempt to link growth and water management planning is the Growing Smarter Plus Act of 2000 which requires counties with a population greater than 125,000 as of the 2000 Census include planning for water resources in their comprehensive plans (ADWR

2010b). Mohave and Yuma are the only two counties outside of the AMAs that fit the population criteria (Jacobs & Stitzer 2006). The Act requires identification of existing, legal and physically available water supplies, anticipated future demand for water, and a determination of how future demand will be met with existing or additional supplies. This provision is important because one of the biggest issues for counties is the lack of a comprehensive analysis of water availability countywide.

> *There isn't a comprehensive look at the entire basin to account for all the growth, where water is, and where water is needed. There is a real need to have some awareness of the physical layout of the basin and where water is, not just what's underneath a single, new proposed development. But, these issues and warnings are not something that is talked about much given the desire for continued growth in the area.- telephone interview, March 27, 2009*

It is not clear if this comprehensive water resources assessment has been completed or not and what, if any, impact such an assessment will have on county development. Besides requiring planning at the county level, the Act also requires that twenty-three communities outside AMAs include a water resources element in their general plans. According to Jacobs & Stitzer (2006) the Act has not yielded improvements in planning or water supply management solutions.

6.3.2.3 Southwest State Information Use Summary

Insights are drawn from the review of CLIMAS's interaction with state water resources agencies that helped influenced policy and planning in the SW. Like the previous discussion about CIG interactions in the PNW, here in the Southwest the knowledge-action system is facilitated by relationship building between the state agency staff and CLIMAS scientists. These sustained interactions are important to increase understanding of climate variability and change for SW states over time and to pave the way for information use opportunities in state drought or water planning.

In the SW, state governors can radically advance the use of climate information in state level planning. For example, in New Mexico Governor Richardson called for a report on the impacts of climate change on water resources and for building resilience to climate change through executive orders. In Arizona, former Governor Napolitano advanced state drought planning through the formation of a drought task force. CLIMAS scientists were active in both states contributing climate information to state agencies and advisory bodies. Second, the close working relationship between CLIMAS and executive level advisory bodies helps improve the translation of science into policy around climate variability and change. These policies have the potential to build resilience to climate variability and change. Lastly, even if close working relationships are established at the county level, without decision making authority that information cannot inform county policy making around water resources.

6.4 Local Water Resource Management: Regional Comparison

The local level analysis of water managers' use of climate information within the simplifying framework of perturbations, organizational response, and stabilizers helped further explain and characterize mechanisms of information uptake by RISA clients in the two regions. Water managers were faced with similar perturbations in both regions: climate variability, climate change, population growth, and endangered species/water rights issues. In response to these perturbations, water managers turned to similar stabilizers including resource buffers such as storage options, increasing or diversifying supplies, and reuse, and to management approaches such as conservation. Where water managers differed was the type of information used and the level of involvement of the organization in support of that information use.

While both PNW and SW water managers used climate forecasts and historical climate data, differences emerged in other climate information sources. PNW water managers incorporated regionally downscaled climate change information while SW water managers more often incorporated tree ring reconstructions. In the PNW the use of climate change information seemed to necessitate support from upper level management and an entrepreneurial approach by staff (see Figure 6.1). The combination of support from upper level management and entrepreneurial employees may reflect the added complexity of using novel information and the process of acquiring that information over time. In contrast, SW water managers using tree ring research seemed to do so with less involvement from the organization as a whole. The use of tree ring reconstructions required approval for the initial commitment of resources but did not seem to be as out-of-the-ordinary for SW water managers (see Figure 6.3). This normalized use of novel information is somewhat surprising given conversations with tree ring researchers that suggest a rather involved process of iteration between water managers and potential users not unlike that involved with the use of downscaled climate change data (CLIMAS scientist, telephone interview, November 4, 2008; CLIMAS scientist, telephone interview, November, 7, 2008). It is possible the intense iteration and organizational learning period took place some time ago which would explain how the use of tree ring data within the organization has matured over time masking some earlier complications. Alternatively, it could be that the tree ring data these water managers used was used more for informational purposes rather than integrated into complex hydrology and system yield models. For example, one water manager used tree ring data to inform a factor of safety on aquifer yield while another used it to inform risk analysis. In comparison, the climate change data used by water managers in the PNW was universally incorporated into hydrology models and individual system models to predict water supply yields. Incorporating the climate change data into system models usually required iteration and sustained interaction over some period of time. In contrast, the use of tree ring data by SW water managers is accomplished fairly independently to inform operation and planning.

Various scales of decision making were introduced into the analysis of local water managers' use of RISA information by incorporating external influences as possible explanations of information use. The introduction of scale included at the most localized level (i.e., just beyond the level of organization) local governments, to regional level water planning, and finally state level water planning requirements for local water systems. In the end, local government did not have much influence on information use in the SW or the PNW. An explanation for this low level of influence is that local water managers are seen as the water experts. Also, there is a level of trust that develops between water managers and local governing bodies. Trust coupled with the view of the water managers as experts often means that water managers are generally the first movers. Water managers react and respond to concerns expressed by local governments but generally they lead in water related decision making, not the reverse.

State and regional level influences differ from local level influences. There is evidence of modest regional level influence in the PNW. The PNW is unique in their approach to regional water resources planning. In Washington in particular, counties play a larger role in planning. In contrast, counties in the Southwest play no real role in water planning for local level water management. Regional planning in the PNW had the potential to influence RISA use because the planning incorporated climate change information and the RISA into the planning process. However, most water managers with the exception of one utility were ahead of this regional planning process in that they were already working with the RISA to examine potential climate change impacts on their systems. For the one utility not already using RISA information, participation in the regional process motivated the use of climate change information. The regional planning process enabled a broader and more integrated examination of climate change impacts on regional water supplies – an examination that was not possible without the regional effort. Oregon also has regional water planning but this effort has not influenced RISA information use. Idaho does not have a comparable regional planning process for local water systems. In summary, while the regional planning process has the potential to motivate information use, for the most part local water managers drove information use at the local level in both regions.

State planning requirements for local systems has great potential to influence local level information use because state laws could require systems to incorporate climate variability and change information into water system planning. However, this potential remains unrealized because none of the states in this study require climate change be incorporated into local water resource planning. State requirements for local water resource planning generally focus on the requirement that systems' plan to ensure sufficient water supplies exist to accommodate growth. Climate variability is normally handled through a separate process either through emergency response (i.e., limited or no planning) or drought planning. Only two of the five states included in this study require extensive local level water planning. In Washington State and in Arizona larger local water systems are required to undertake water resource planning. Washington State's planning requirements are integrative focusing on water supply reliability planning across multiple factors (i.e., including growth and variability in both quantity and quality) while Arizona separates the planning into water supply that accommodates growth, drought planning, and conservation planning. Given the more rigorous state level planning requirements in Arizona and Washington (and the size and location of the water systems), one might reasonably expect local level water managers in these states to have higher rates of planning and to use more climate information than water managers in other states. Unfortunately, there were too few stakeholders interviewed to make a determination about the effects of state level planning requirements on rates of planning or on rates of climate information use among RISA clients. Still, while a quantitative analysis of RISA clients is not possible, qualitatively it is clear that state planning requirements do not explain why these water managers use tree ring data or climate change information since the use of this information goes above and beyond any state planning requirements. This seems to indicate, that for clients in particular (and possibly non-clients) who use RISA information, the relationship with the RISA plays an important role in information use supporting the findings in Chapter 5.

While the small number of RISA clients interviewed for this study makes it difficult to quantitatively assess the effect of state level planning requirements on information use, survey data permit this assessment. To determine if state level requirements shape planning and information use among non-clients, I test the hypothesis that state level requirements play a role influencing the high rate of local level planning in Washington and Arizona in comparison to other states. Indeed, of the PNW states Washington had the highest rate of non-clients who reported having long-term water management plans (67%) overall and a higher rate of planning than Oregon, the next highest (χ^2=4.53, (1, n=403), p<.05). In Arizona, water managers reported higher rates of long-term water planning than in New Mexico (45% vs. 36%). These data suggest there is a relationship between state planning requirements and rates of long-term planning among non-clients. However, when forecast information use and climate change information use are examined, the data suggest a different conclusion. Non-clients from Oregon reported the highest rates of forecast information use, more than Washington, the home state of the RISA (χ^2=3.93, (1, n=413), p<.05), where planning requirements are more stringent. In the Southwest, data indicate water managers in New Mexico use forecasts at a slightly higher rate than Arizona water managers (17% vs. 14%) despite the fact that Arizona is the home state of the RISA and that it has more stringent planning requirements. This same pattern is observed in the use of climate change information by local water managers. In Oregon, water managers use climate change information at higher rates than Washington water managers (χ^2=7.42, (1, n=411), p<.01). In the Southwest, New Mexico water managers use climate change information at higher rates than Arizona water managers (19% vs. 11%). This suggests that climate information use in general and RISA information use in particular is not explained by state planning requirements. The conclusions reached in earlier in this chapter and in the previous chapter better explain RISA information use.

6.5 Effective Knowledge-Action Systems for Building Resilience

The examination of RISA information use demonstrated that RISAs help build resilience to climate variability and change across scales through knowledge-action systems. RISAs help communicate, mediate, and translate climate information ultimately improving the utility of the information for water management. While the information does not itself build resilience, science informs policy and decision making that leads to increasing resilience.

The analysis also yielded important insights into additional requirements for effective knowledge-action systems that help build resilience to climate variability and change. These insights build upon the work of Cash *et al.* (2003) which is focused on creating effective knowledge-action systems by for sustainable development. The conception of knowledge-action systems by Cash et al. (2003) is focused on information production and boundary management. Clearly, results indicate the production side is important as is the boundary work facilitated through building relationships between information producers and potential users. However, while the information production and boundary work are critical, more attention must be paid to understanding and bolstering the action side. For this reason, Cash *et al*.'s (2003) conception of knowledge-action systems for sustainable development is not sufficient to be directly applied to the area of building resilience to climate variability and change for water resource management. Results from this analysis suggest building resiliency to climate variability and change and other water stresses knowledge-action systems also require:

a) Technical, human, and financial capacity to enable the knowledge users to make use of information

b) Leadership by knowledge users to be able to influence the use of information in their policy sphere or in higher policy spheres

c) Appropriate authority at the appropriate scale. Knowledge users must have the authority over water management planning and decision making or knowledge-action systems aimed at building resiliency will be ineffective because action opportunities are limited.

d) Interaction across multiple scales. Building resilience is enhanced when knowledge-action systems are formed across multiple decision scales from the local to the state level. Furthermore, improved potential for action is achievable when knowledge-action systems are able to inform the highest policy spheres.

The study of RISAs and their clients indicates that by focusing on improving all aspects of the knowledge-action systems (i.e., from knowledge production to knowledge use), RISAs can help build resilience in water resource systems.

Chapter 7

Conclusions

RISAs employ an interactive, stakeholder-driven research approach to improve the usefulness and usability of information for their clients. Indeed, this research found a high rate of information use among RISA clients in both regions. These water managers represented varying interests from local water utilities, to county water planners, and finally, to state level water resource managers and planners. Indeed not only did RISAs achieve excellent information use in general among their clients, but they were able to serve quite varied information needs of water managers across scales and to some extent, distance. This breadth of successful information provision to clients is a strength of the RISA approach.

Another strength of the RISA approach is the interdisciplinarity of the climate information provided. RISAs are adept at exploring cross-sectoral climate impacts of interest to clients. For example, in the PNW RISA clients used climate change impacts information that incorporated aquatic habitat impacts into instream flow and water rights negotiations. Climate change impacts on the energy-water nexus were also of interest to RISA clients in both regions.

7.1 Characteristics of RISA Information Users

While there was a high rate of information use among RISA clients, these water managers were different in some respects from the broader population of water managers surveyed who used RISA information (non-client users) and very different from the broader population of water managers surveyed that did not use RISA information (non-client non-users). RISA clients who were local level water managers managed larger systems that were physically closer to the RISA in comparison to non-RISA client local water managers who used RISA information. Comparing RISA client information users with non-client non-users revealed an order of magnitude difference in system size and distance to RISA. The broader population of water managers surveyed not using RISA information managed on average much smaller water systems that were physically located much further from the RISA. On the other hand, RISA clients were predominantly managers of large, surface water systems. This suggests that a size threshold exists such that local level water managers must be large enough to have sufficient capacity to either engage with the RISAs as clients or use RISA information as non-client users. They must also be close enough to be able to interact with RISAs or know of the availability of the information. Lastly, they must also perceive a large enough potential threat or vulnerability to their water resource and understand how climate information might help manage the threat to avail themselves of RISA information. Table 7.1 summarizes these findings.

Table 7.1 Summary characteristics of RISA client and non-client information users.

	RISA Clients	Non-clients	
Characteristic	Users	Users	Non-users
Local Water Managers			
Average System Size	Largest	Large	Smaller
Average Distance to RISA	Closest	Close	Further
Primary Water Source	Surface Water	Mix	Groundwater
State Water Managers			
Average Distance to RISA	Mix	NA	NA

RISA clients who were state level water managers are not constrained as much by distance; yet, information use is enhanced when water managers are closer. These findings challenge the notion that RISAs are able to serve large regional information needs when after twelve years or more in operation, there remains a clear home-state information use bias. While some impacts assessment may be appropriate for the regional scale, information users on the whole seek more localized (e.g., basin scale) climate information.

7.2 Regional Comparison

Comparing RISAs across two regions revealed interesting differences in regional approaches to information provision. A more collaborative approach dominated in the PNW while a more consultative approach dominated in the SW. In particular, collaborations seem to be key to the communication, translation, and mediation of climate change information to enhance the usability of that information for clients, irrespective of whether the client hailed from the state, regional, or local scale of water management decision making. More entrepreneurial water manager clients coupled with a supportive decision environment at the site of information use facilitate the collaborations from the water manager perspective.

While collaborations dominated in the PNW, consultation was the dominant approach in the SW. This approach seemed to reflect not only the maturation in the use of forecasts and tree ring reconstructions by RISA clients in the region but also differences in the way water managers seek information in the SW compared to the PNW. Water managers in the SW maintain more separation between the science and the policy spheres while PNW water managers are more willing to engage in the “messiness” that characterizes the scientific process. PNW clients engage CIG scientists to better understand the limits and potential of the science and to help shape the research agenda more than water managers in the SW. Only one CLIMAS client in the SW expressed a willingness and desire to engage more with RISA scientists to narrow rather than eliminate the gap between science and policy. This SW water manager also expressed an interest in helping set the CLIMAS research agenda.

The overall collaborative versus consultative regional patterns held among the broader population of water managers who use RISA information (i.e., non-client users). Non-client users in the PNW reported more collaboration with the RISA while SW non-client users reported more use of the RISA purely as a source of information. Results also indicated that more non-client RISA users in the PNW use climate change information than in the SW. This finding among non-client RISA users corroborates the connection found among RISA clients and supports the contention that collaboration is a precursor to the use of climate change information for both non-client and client users. The link between collaboration and climate change information use suggests a potential challenge for the provision of climate change information to non-client water managers not currently using this information. It suggests that, at present, climate change information use is a much more intensively iterative process. The intensity and investment from the RISA, their clients, and non-client users likely contributes to the observed lower rates of information use across the PNW in comparison to rates of information use in the SW. Thus, a trade-off was observed between the high level of iteration and collaboration in the PNW that resulted in a lower proportion of RISA information use compared to lower intensity iteration and higher rates of RISA information use observed in the SW. This again challenges the notion that RISAs can adequately provide climate information, particularly climate change information, across large regions. This finding has the potential to inform larger climate change impacts assessment efforts suggesting that climate change information use, particularly use at the local level, is more contingent on established, well-maintained, collaborative relationships. Climate change information use by RISA clients at the state level also requires collaboration but distance was less of a factor in predicting information use. This suggests it is possible to usefully reach state level information users through a regional assessment approach and regional collaborations but it is much more difficult to reach local level decision makers across the expanse of a larger region.

7.3 Boundary Management

One of the hallmarks of the RISA stakeholder-driven approach is the active management of the boundary between science and policy through communication, mediation, and translation of scientific information. Supporters of the stakeholder-driven approach contend that it results in improved information use among stakeholders. Indeed, high rates of information use were observed among RISA clients. What is more interesting is not confirming the expected high rates of information use, but rather testing specific and tangible improvements in information provision resulting from boundary work employed in this stakeholder-driven model. By examining use and non-use among two groups—clients and non-clients—it was possible to derive specific and tangible differences attributable to the impact of boundary work. For example, infrequent interaction coupled with one-way communication could not overcome product-related barriers to information use such as lack of salience or too much uncertainty or context-related barriers such as having other, higher priority issues. On the other hand, infrequent interaction coupled with two-way communication did overcome these product- and context-related barriers to information use.

Results suggest that a managed boundary is important particularly when it comes to conveying information that is inherently uncertain, such as forecasts and climate change information. When the boundary between RISA scientists and their clients is managed, even though concern about uncertainty persists among the water managers, the information is used. This finding has potential implications for other areas where information use is lower because of perceived high levels of uncertainty. Boundary work also helped overcome context barriers to information use. When scientists and clients interacted and engaged in two-way communication, context-related issues persisted but again information was used in spite of the barriers. For client non-users, infrequent interaction and one-way communication were key impediments to information use. Thus, the missed opportunity for greater boundary management decreased information use. This pattern was repeated for non-clients non-users. Interaction was a key driver of information use among non-clients and the lack of interaction was a key barrier among non-client non-users.

Boundary management was also found to be critical to the co-production process leading to enhanced information use. For example, in the PNW water managers and RISA scientists worked iteratively to link downscaled climate information to water system hydrologic and system models to develop surface water yield projections. Without this close working relationship advancements in downscaling climate information achieved by the RISA scientists would not have been effectively linked to real-world water system impacts. From the water manager perspective, the downscaled climate change information provided useful bounds on the uncertainty of climate change impacts to their water systems. This bounded uncertainty helped water managers anticipate potential climate change impacts and advance their water system planning and management. In the SW, CLIMAS scientists described working with local water managers in New Mexico to overcome barriers to the use of tree ring reconstructions to enhance water supply planning. The co-production process involved RISA scientists and water managers working together to iteratively advance the tree ring reconstructed stream flow information to more seamlessly integrate with the water manager's existing water supply planning models. Ultimately, the co-produced information helped extend the historical record of climatic variability and resulted in enhanced water supply planning.

7.4 Building Resilience & Knowledge-action Systems

Interestingly, despite differences observed among client and non-client users water system size, proximity to the RISA, and water source, the underlying motivation for RISA information use among local water managers was similar. Water managers sought information to help manage perceived threats to the resource from climate variability and change and exhibited a willingness to collaborate with RISA scientists and others to obtain RISA and other climate information in an effort to manage risk. Client and non-client RISA users also exhibited a commitment to planning and, at least among clients, a more decentralized decision making structure that facilitated information use. These observed characteristics that motivate information use among RISA users—perception of risk, information seeking, planning, and decentralized decision making structures—are indicators of organizational resilience potential. This suggests that local water manager clients and non-client RISA users may exhibit more resilience potential than water managers who do not use RISA information. So, even without RISA information use, these water managers may already be more resilient to the threats posed by climate variability and change than their smaller, non-RISA using peers. The willingness to use novel climate information and the observed information seeking behavior also points to a departure from the more traditional view of water managers as conservative and risk adverse, favoring routine, established practices, and local knowledge. Clients using RISA information may be better described as neo-conservative given the likelihood of (1) embracing new knowledge, (2) searching beyond their organization for information, and (3) enhancing water system planning to better manage risk.

Given the larger system size characteristic of RISA users, one could speculate RISA users have more resilience potential without this research simply because larger systems generally have more capacity than smaller systems. However, more important is the observed improvement in the robustness of decisions made using RISA information. Actions to buffer against resource perturbations taken by these local water manager clients and non-clients using RISA information are more robust signaling enhanced resilience to climate variability and change. The increase in resilience is derived from the buffering actions undertaken in response to perceived or actual changing climatic and resource conditions (i.e., non-stationarity assumptions). The increase in robustness of the decisions is due to the use of RISA climate information informing decision making whether or not tailored to specific system needs. RISA information provides a longer planning view by examining past climatic variability or by examining future potential climate change than is afforded by instrumental records alone. Furthermore, RISA information provides a means to quantify and explore potential water management scenarios (i.e., bounded uncertainty) grounded in science to enhance planning. Bounding the range of uncertainty is useful to local water managers who must justify costs and policy changes to elected boards and commissions as well as to their rate payers and ultimately improves resilience of these systems.

The use of RISA information also has important implications for state level water managers through knowledge-action systems. RISA engagement with state level water managers helped transition PNW state departments of water resources from no use of climate change information to use of climate change information even including new planning requirements that incorporate climate change. State governors played an important role in advancing the use of climate information in the SW. Here too RISAs helped provision climate information that informed decisions to enact new planning requirements that incorporate climate information. RISAs, acting as part of a knowledge-action system, helped states build resilience potential to climate variability and change.

The local and state level analysis of knowledge-action systems suggested four additional components are required to enhance the effectiveness of knowledge-action systems for building resilience to climate variability and change for water resource management. These four components focus on the action side of the knowledge-action system and include: (1) building technical, human, and financial capacity at water management organizations; (2) leadership by knowledge users; (3) appropriate authority at the appropriate scale; and, (4) interaction across multiple scales. Knowledge-action systems experience lower rates of effectiveness if water managers lack the capacity or authority to incorporate climate information. Lower capacity limited information uptake among RISA users and curtailed information use among smaller systems that generally lacked the capacity of their larger peers. Knowledge-action systems were enhanced when information users had the authority to use the information directly as observed more often at the local scale of decision making. For state level decision makers, leadership was important to improve the effectiveness of the knowledge-action system. Knowledge-action systems were more effective if state level water managers valued the information and advanced its use.

7.5 Future Research

Stakeholder-driven research is generally praised for better matching needs of information users and ultimately leading to more information use. The variation observed in this study suggests an important question: what information products are suited to this approach? In other words, what characteristics of the information product suggest a stakeholder-driven research model is required to improve usability of that information? Is it information that is highly uncertain or interdisciplinary? The RISAs seem to thrive in this uncertain, interdisciplinary space but in the end, their products are mostly used by larger water systems and state level water managers. Given limitations in staff time and budget this focus makes sense, but it leaves a huge segment of the population of potential stakeholders underserved. Should there be more attention given to serving these smaller systems perhaps by partnering with Water Resources Research Centers and their staff (or other research or professional organizations) in each state within each RISA region? There is a need to better understand what information sources are available for local, state and regional water mangers and to consider opportunities for partnering to expand networks and information provisioning across a range of potential user needs.

Another outstanding question is whether we can empirically test if RISA information is inherently "better" than other climate information not provided by a RISA. Performing this empirical test would be one way to evaluate if co-produced information offers a greater return on resilience preparedness than information that is produced using non-interactive approaches. This research would also help differentiate between the effects of improved information compared to characteristics of the water management system in fostering resilience. In other words, this research could illuminate the relative importance of co-produced information versus capacity building (or other water system needs) in building resilience to climate variability and change.

Also, much more research is needed to understand the potential broader societal impact that may be achieved through RISA engagement with state level water managers. This suggests a need for deeper exploration of RISA engagement with these individuals perhaps using a more structured framework and including more state agencies beyond departments of water resources. This approach would enable a more thorough examination of state climate information use (e.g., natural resources departments, transportation departments, etc.) to assess the breadth of existing information use and to suggest opportunities for expanding information use to other departments. Such an approach might provide some insights into how states might reasonably expect to comprehensively respond to potential future climate change impacts and ways to improve state's long-term resilience. It might also be useful to include states not using RISA information for comparison or as a control case (or cases).

Lastly, this research raised an important question about the assumption that RISAs can adequately provide climate information, particularly climate change information, across large regions. Given that existing emissions have already committed the planet to some unavoidable climate change, there is a keen need to understand potential climate change impacts to help build resilience across multiple decision scales. The question remains: what is the best scale at which to provide information to maximize usability? This research may also have implications for the impending re-launch of the National Climate Change Assessment particularly with respect to the usability of information and stakeholder relationship building at the local and regional level.

Chapter 8

Recommendations

Research findings indicate the overall rate of RISA information use is low despite rising climate-related risks to water resources. While the rate of RISA information use is low, when information is used, water resources planning and management decisions made to buffer against the vulnerabilities posed by climate variability and change are more robust. This suggests that an increase in the use of RISA information would help water managers better respond to the multiple stressors including the climate-related stressors affecting the overall resilience of their water systems. In addition, results indicate RISAs are already contributing to and have the potential to enhance their contributions to building resilience to climate variability and change in the water sector through knowledge-action systems. Recommendations for improving RISA information use and facilitating the development of more effective knowledge-action systems to build resilience are the subjects of this chapter.

8.1 Water Managers Use a Variety of Information Sources

Of the larger population of water managers (n=660), only 7 percent use RISA information and of those, most are larger systems proximate to the RISAs. The low rate of RISA use does not reflect a narrow definition of use. Rather, the measure of RISA use encompasses information use for both general purposes and specifically for climate related information. In reality, water managers use a variety of other information sources instead of and in addition to RISA information. When asked about the information sources they use most often to assist them with managing their water system or for general information, water managers overwhelmingly indicated they obtained information from state environmental or water resources agencies or departments first, followed by water sector specific associations like the American Water Works Association or state rural water associations. Water managers used state agencies and water sector associations three times as much as the next most often selected information source, engineering consultants. Water managers tapped engineering consultants ten times more often than RISAs and state agencies and water sector associations thirty times more often than RISAs. RISAs consistently ranked at or near the bottom along with universities as a source of general information to assist water managers (see Figure 8.1).

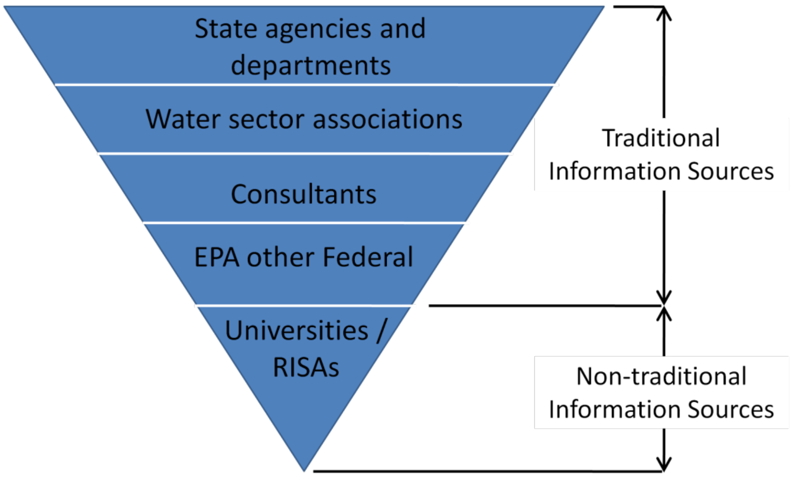

Figure 8.1 Water systems information use pyramid.

The much lower rate of RISA use among the larger population of water managers was expected given RISAs produce more specialized information and RISAs are not a traditional information source used by water managers. Water managers traditionally seek information from state agencies and departments, water sector specific associations, consultants, and Federal agencies like the EPA. This pattern of information use stems from the fact that water managers operate within a heavily regulated environment. This regulatory environment means there is a very real and practical need for information that: (1) ensures compliance with regulations enforced by state agencies and departments; (2) supports reporting requirements that necessitate interaction with state agencies that have enforcement authority; and, (3) supports managers' procurement of financial or technical assistance to facilitate compliance and avoid penalties. This close connection with water managers and their systems means state agencies and departments often have a good understanding of the primary issues facing the water sector in their state.

The use of information from water sector specific associations arose because associations provide needed technical information and assistance to help water managers meet regulatory requirements and build capacity. This information includes manuals for specific water treatment processes, operator training, continuing education, etc. In addition, water sector associations also often track legislation and advocate on behalf of the water sector to direct attention to resolving issues. Like state agencies and departments, the high level of interaction with water managers across a range of issue areas and needs means water sector associations also have an enhanced awareness of the stresses water managers face. Water sector associations and state agencies and departments form the top of the information pyramid along with other traditional information sources shown in Figure 8.1.

CWS managers rely on consultants for many of their planning and engineering needs. Smaller systems often rely exclusively on consultants for a variety of tasks from engineering treatment and distribution systems to generating water system plans to operating water plants. Larger systems also rely on consultants for a variety of tasks but often have more staff to manage projects than smaller systems that often depend on consultants for turn-key services. Because of the work undertaken on behalf of water managers and their water systems, consultants are also often cognizant of water system issues. Their fiduciary relationship with water managers means consultants have an interest in addressing and resolving issues to serve their clients but do so often through contractual arrangements.

Universities and RISAs, often housed at universities, represent a more specialized information resource used in rare cases when consultants or other more traditional resources are not well-suited to the task. Results also indicate the use of this specialized information is facilitated through the client-scientist relationships. In addition, RISAs may offer a potential financial advantage over consultants in some circumstances when, for example, RISAs act as information brokers. When RISAs act as information brokers, the information is often “free” to potential users because the development of the information is funded by other sources and the information itself is meant for wider consumption. This differs from the situation where RISAs act as co-collaborators developing more tailored information for one or more stakeholders often with some financial support from the stakeholder. Even though RISAs offer “free” information, this has not yet translated into widespread use of RISAs as information sources. Given the differences in incentives (routine regulatory compliance vs. novel endeavors), contracting arrangements and timelines (business oriented, short-term vs. academic oriented, long-term) and the underutilized “free” benefit RISAs provide, it is not altogether unexpected that RISAs sit squarely at the bottom of the information/resource pyramid.

8.2 Strategies to Increase RISA Information Use

Applying what was learned through analysis of non-client and client information use, the next sections outline three strategies for improving information use among local water managers. Two of these strategies approach the problem from the perspective of what RISAs can do to improve information use directly. The direct action strategies are: (1) partnering with traditional information providers and (2) doing more of the same but concentrating on consultation. A third strategy approaches the problem from the perspective of a supply-driven demand approach that relies upon external influences on local water managers to increase demand for climate information through policy change. Ultimately, RISAs contribution to knowledge-action systems at multiple scales of decision making including at the state level may build momentum and enhance climate information use in state and local water planning.

8.2.1 Strategy 1: Partnering Using Existing Networks

Given the low overall rate of RISA use compared to the high rate of use of more traditional information sources, a key non-regulatory strategy would be to create an improved dissemination effect for RISA information through the establishment of more productive, synergistic relationships with traditional information provider networks. State agencies and water resource departments enjoy a high rate of information use by water managers. RISAs are already engaged with state agencies and departments and working with agency staff to provide useful climate information and advice. These existing relationships are yielding dividends by increasing state level use of climate information. However, these existing relationships are not translating into increased information use among local or regional water managers even though demand for climate information exists. For example, results indicate a relatively large number of water managers use forecasts but only a small fraction use RISA information. That is, among all non-clients, 22 percent use forecasts of which 15 percent use RISAs. There is also a larger demand for climate change information a third of which is provided by RISAs. Among the larger population of water managers 9 percent use climate change information of which 30 percent use RISAs. How can RISAs fill this demand and enhance their utility to local water managers?

Instead of muddying the state level relationships, a better strategy is to build stronger ties with water sector associations. Unlike state agencies which often have an adversarial relationship with local water managers due to the regulatory and compliance driven nature of the interactions between water managers and agency staff, water sector associations often have more collegial relationships due to their work to provide technical assistance and capacity building for water managers. Water sector associations also offer an advantage due to their strong, well-established networks with water managers.

This strategy begins with developing closer ties between RISA outreach personnel and RISA scientists and water sector association staff to identify how RISA information may be useful to association members. For example, rural water associations often hold training sessions for their members. If interest in climate information develops, one or more training sessions could be devoted to educating water managers about how climate information may help them better respond to climate-related stressors. Building relationships with water sector associations may help increase information use among a range of systems from smaller systems served by rural water associations to larger systems that may be members of a state water utility association. This strategy may also be a useful way to bolster information use in states other than the home state of the RISAs by helping RISA personnel tap into the existing networks associations have with water systems in those states. Starting with the larger systems in adjacent states (i.e., New Mexico, Idaho, and Oregon) that use RISA information at much lower rates than their peers in RISA home states (i.e., Arizona and Washington) is a reasonable first step. Working within association networks and gradually building and increasing RISA-water manager interactions and collaborations with these larger systems, may increase information use in adjacent states given the tight association between interaction and collaboration and information use.

8.2.2 Strategy 2: More Intense Consultation

RISAs engage in a number of different research approaches from less interactive but use-inspired basic research to very collaborative stakeholder-driven research to brokering information. The flexibility of being able to engage in a variety of interactive approaches is a strength of the RISAs and capabilities for such diverse methods of engagement, knowledge generation, and knowledge dissemination should be preserved. However, resources (human and financial) are scarce and extending RISA information use may strain that resource base. A strategy to maximize the use of available resources but extend the reach of the RISAs to the broader population of water managers is to engage in less intense but more consultative or brokering types of relationships. This strategy would enable the limited RISA staff, time, and resources to be distributed across a larger population of potential information users, potentially leading to more distributed use among their geographic service area. This strategy is informed by the regional RISA comparison, which showed greater rates of information use in the SW coupled with less intense interactions compared to lower rates of information use in the PNW coupled with more intense interactions.

The other way to think about this strategy is that it provides an efficient and affordable way to extend the use of RISA information. The hard work of developing information that is useful for water managers has seen considerable progress over the last decade. Now is the time to invest in encouraging more water managers to use that information. It is possible RISAs are not well structured to play this larger information provision role, which might be better suited to an organization tailored to operationalizing RISA and other climate information. Yet, there is clearly a need to continue to build the regional RISA presence through information provision efforts like those already in use including semi-annual forecasts meetings, bulletins, newsletters, and other means of outreach. It may be that RISAs develop partnerships with organizations that put more emphasis on outreach and less emphasis on developing new knowledge as suggested in the previous section. Partnering would help balance university-related pressures that act to constrain RISAs' outreach efforts since universities generally incentivize and reward publishing new knowledge in peer-reviewed journals over outreach.

This strategy has one significant caveat. Research findings suggest some types of information may require more collaboration than consultation from the RISAs. For example, results indicate use of climate change information required more intense collaboration. It is possible that extending the use of information about the potential impacts of climate change on local water systems cannot be accomplished without continued dedication of high levels of RISA resources. In light of this finding and the emphasis of academic institutions on creating new knowledge, it may make more sense for RISAs to work on the cutting edge advancing the state of knowledge rather than operationalizing existing or established science. This caveat gets to the heart of the evolution of the RISA vision and to the need to clearly articulate the best fit for the RISAs in light of the burgeoning demand for and potential supply of climate information from a variety of sources that target a variety of needs (e.g.., National Climate Services, consultants, etc.). In the meantime, states are bolstering their own climate change information provision capacity through efforts like the Experimental Program to Stimulate Competitive Research (EPSCoR) efforts in Idaho and Nevada.

8.2.3 Strategy 3: Policy Change

RISAs represent an evolution in the approach used to collaboratively produce or co-produce information providing much needed synergy between the supply and demand for climate information. However, this evolution has not generated widespread use of climate information beyond RISA clients as evidenced by the position of the RISAs at the bottom of the information resource pyramid among non-clients. This is in spite of the fact that there is immense potential for the use of climate information to support water resources decisions and an apparent demand for climate information not provided by RISAs (See Section 8.2.1).

One of the primary impediments to climate information use as suggested by the survey results is structural. That is, there is an established infrastructure for traditional information sources with established contact points, linkages, and consistent, compliance driven interactions. For traditional information sources, the infrastructure for the supply of and demand for information was formed in response to regulations and is sustained by regulatory compliance. The regulatory-driven demand for climate information is missing: the present demand that exists for climate information is smaller and reflects individual water manager decision needs and RISA outreach. RISAs mitigate the lack of access to this established, regulatory-driven infrastructure through advancement in the supply side of information—producing information that is useable—and advancement in the demand side for information—linking with stakeholders. Because RISAs employ a user-driven approach, they have developed a growing network of climate information users. But according to the results from this research, that network is limited. Direct action strategies for increasing the network of RISA users have already been discussed. In addition to direct actions by the RISAs, results suggest policy changes may also be needed to foster the use of climate.

A regulatory or policy driver could take several forms. An example of a regulatory driver is requiring climate information to be used in water system planning at the local level or in water resource planning at the state or regional level. To date, states have taken a very conservative approach to initiating mandatory planning requirements for local water systems. Thus far only one state, California, has enacted a regulatory driver tying state funding for water projects to the inclusion of climate change in water resources planning at the local level. Mention of consideration of the same approach in the state of Washington, drew consternation from water managers in attendance (telephone interview, May 22, 2009). The consternation reflects the real challenges water managers face in terms of having sufficient resources to meet existing regulatory requirements. These challenges are not an attempt to deflect additional regulation, but rather a reflection of the enormous need for more infrastructure investment to maintain and replace existing infrastructure and bring existing systems into regulatory compliance.[1]

New requirements at the federal level may spur further integration of climate information into planning around adaptation. The American Recovery and Reinvestment Act of 2009 requires states to designate 20 percent of Drinking Water State Revolving Fund (DWSRF) grants for "environmentally innovative" or green projects.[2,3] Examples of projects that satisfy the "environmentally innovative" requirement include projects that enable utilities to "adapt to the impacts of global climate change."[4] It is too early to tell if this initiative is increasing demand for climate related information or increasing the preparedness of water systems to manage climate-related risks. The Federal Government could take a stronger position explicitly requiring climate change be considered in hazard or other planning programs as a condition of funding as an alternative to solely relying on state action. Doing so would ensure more uniformity in planning for climate-related risks across the United States and would avoid the need to create an entirely new program.

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[1] USEPA, *The Clean Water and Drinking Water Infrastructure Gap Analysis,* http://water.epa.gov/aboutow/ogwdw/upload/2005_02_03_gapfact.pdf (September 2002). The United States House of Representatives recognizes the need to increase infrastructure funding and recently voted to pass H.R. 5320, The Assistance, Quality, and Affordability Act of 2010. See http://energycommerce.house.gov (Thursday, 29 July 2010).

[2] Quoted from a guidance document published by the USEPA on implementing the American Recovery and Reinvestment Act, March 2, 2009, available at http://water.epa.gov/aboutow/eparecovery/upload/2009_03_31_eparecovery_STIMULUS_Guidance_Green_Reserve-2.pdf

[3] Retrieved from http://water.epa.gov/aboutow/eparecovery/ on September 5, 2010.

[4] Quoted from a guidance document published by the USEPA on implementing the American Recovery and Reinvestment Act, March 2, 2009, available at http://water.epa.gov/aboutow/eparecovery/upload/2009_03_31_eparecovery_STIMULUS_Guidance_Green_Reserve-2.pdf

If states or the Federal Government initiated policies to require consideration of climate change for local water system planning, the new requirements could in fact challenge the ability of RISAs and other climate information providers to supply that new demand. This reinforces the need to examine how non-traditional information providers like the RISAs fit within the established traditional information supplier framework that is more regulatory driven. If new climate-related regulations were passed at the state level, better integration of non-traditional and traditional information sources would be required (see Section 8.2.1). The focus of the new National Climate Service on providing climate information in more of an operational format could be a better use of resources than relying on universities and RISAs. This arrangement would leave RISAs to continue innovating (such as working across disciplines) and others to supply what may become standard climate information needs in the future.

An important consideration to strengthen states' ability to manage climate-related risks does not involve new policies to require the inclusion of climate change in planning. Rather, it asks how we manage resources if fundamental understanding of the resource itself is limited and the ability to manage water resources is hamstrung by existing legal frameworks and outdated practices. For example, the Oregon Department of Water Resources estimates a lack of information for about 25 percent of the state's surface water resources and about 75 percent of the state's groundwater resources (Norris 2006). The lack of data and information makes it difficult to manage the water resources in these areas since there is insufficient information about water availability to use to compare against existing and proposed water rights. The lack of information has contributed to over-allocation of water resources in some basins (Neuman et al. 2006) necessitating pumping restrictions because too many water permits were issued relative to the amount of water available (Zaite 2009). Climate change impacts will likely add to the management issues already evident in these basins. However, to effectively manage water resources the states must first develop the water resources assessment databases for the entirety of the state's water resources and then reconcile administration of those resources with the available demand.

A second important consideration for states is to advance state and regional water resources planning. Local water resources planning particularly among larger systems is quite advanced reflecting the high level of perceived risks to local water systems and to their ability to reliably supply water to their customers. Advancing local planning efforts via new planning requirements is important. However, local planning efforts can be undermined if it ignores regional or other impacts on the water source or legal instruments that impact the water source beyond the control of the local water system. For example, the issuance of groundwater withdrawal permits without a prior appropriation framework means that more senior surface water rights or groundwater pumpers have no recourse to preserving their right to withdrawal waters if they are impacted by more junior groundwater withdrawers. This suggests there is a need to bolster state and regional water planning efforts to complement the local planning already in place given the increasing demands on water resources and the potential impacts of climate change. Advancing regional or state level planning would help provide a framework for identifying counterproductive interactions and water resource issues and for aiding their resolution. Furthermore, advancing the state of water resource planning would provide a better foundation for states to incorporate climate change into water resource decision making such as taking potential climate change impacts into account in administering water rights. Without this water resource assessment and planning framework in place, consideration of climate change is made more difficult or must be done piecemeal which may undermine decisions that are made using a smaller viewpoint.

8.3 Towards More Effective Knowledge-Action Systems to Build Resilience in the Water Sector

The local and state level analysis of knowledge-action systems suggested four additional components are required to enhance the effectiveness of knowledge-action systems for building resilience to climate variability and change for water resource management. These four components focus on the action side of the knowledge-action system and include: (1) building technical, human, and financial capacity at water management organizations; (2) leadership by knowledge users; (3) appropriate authority at the appropriate scale; and, (4) interaction across multiple scales.

8.3.1 Building Technical, Human, and Financial Capacity

Knowledge-action systems experience lower rates of effectiveness if water managers lack the capacity to incorporate climate information. Lower capacity limited information uptake among RISA clients and curtailed information use among smaller systems that generally lacked the capacity of their larger peers. Staff technical and scientific capacity support the incorporation of information at all levels of decision making. However, even with increased capacity, incorporating climate change information is not always straight-forward. Even sophisticated users of climate information including those at large, local water utilities or state or county water management agencies must devote time and effort from the user side to facilitate the integration of information. For example, staff at the Washington Department of Ecology translated CIG climate science and moved the science into the policy-making sphere, work that contributed to the decision to contract with CIG to undertake a statewide climate change impacts assessment and investigation of adaptation options. Ensuring larger systems have the resources, staff, and time available to address climate-related risks is key to developing the action side of the knowledge-action system.

Building capacity at large community water systems and state and regional water planning entities is important, but attention must also be paid to smaller system needs. Small systems are especially vulnerable from climate variability and change impacts because they often lack a diverse water supply and have few staff and resources to plan or respond to climate-related risks. As a result, these systems often require emergency assistance during droughts, a need which may increase with climate change impacts. Improving the capacity of small systems is an important strategy to bolster the resilience of these water systems and to support a wider knowledge-action network.

8.3.2 Leadership by Knowledge Users

Research results indicate that leadership on the action or information use side of the knowledge-action system is important to advance knowledge use. To build effective knowledge-action systems information providers must recognize that knowledge use is not a passive activity; rather, bringing new information into an organization requires leadership. RISAs have an advantage in this area because of the relationship building that takes place between RISA scientists and their clients that facilities information use. For example, county leadership in Washington State helped ensure the regional planning effort included incorporating climate change impacts into water resource planning (telephone interview, May 29, 2009). Leadership is also important to building effective knowledge-action systems at the state level. For example, without the leadership of Idaho Department of Water Resources (IDWR) staff who used RISA information to help influence state representatives in their decision to include climate change impacts information in a new state basin planning effort, knowledge use and action based on that information would have been severely curtailed. In other words, without IDWR staff willingness to champion climate change issues at the state legislature and influence policy it is unlikely climate change information would be integrated into IDWR water resource planning efforts. Knowledge-action systems are more effective if water managers (i.e., information users) value the information and advance its use.

8.3.3 Appropriate Authority at the Appropriate Scale

Authority to take action to incorporate climate information or respond to climate-related risks varies depending on the scale of decision making. Knowledge-action systems are enhanced when information users have the authority to use the information directly. For example, at the local level, the manager of the water system is seen as the expert on water resource issues by members of the water system governing body (e.g., city council). This view of the water manager as an expert coupled with the trust that develops between the water manager and the governing body enables the water manager to take action in a more direct manner when risks are identified. As such, local water managers are often well-positioned to make use of climate information to address climate-related risks making for effective knowledge-action systems.

In many states, counties do not have the authority to manage water resources except in a very limited way such as approving land development plans. For example, counties in the SW play no real role in water planning for local level water management. Developing knowledge-action systems with county level planners in the SW did not result in action even though knowledge was shared because of the limited authority. The situation is different in Washington State where counties play a larger role in planning and where knowledge-action systems are more effective at the county level.

The authority of state level water planners generally facilitates incorporation of climate information into decision making. In fact, research results indicate development of knowledge-action systems were quite effective at the state level. State governors are also taking more direct action to facilitate incorporation of climate information. In general, understanding how water resources are managed in each state is important to inform the development of effective knowledge-action systems to build resilience to climate variability and change in the water sector.

8.3.4 Interaction across Multiple Scales

Results suggest knowledge-action systems are more effective if the systems are developed across scales of decision making. For example, building knowledge-action systems with local water managers in Washington State facilitated the development of a regional scale knowledge-action system and ultimately informed state level decision making. Developing cross-scale networks builds momentum for incorporating information across decision making scales because the decision scales influence each other.

Another important reason for developing multi-scale knowledge-action systems is the nature of the climate risk. While it is true impacts are local, responses must be not only at the local level but also at the regional and state levels. Because the climate risk is diffuse, integrating cross-scale knowledge-action systems is a necessary step to create more effective and informed responses to climate-related risks.

Appendix 1: Interviews and Surveys

This appendix includes copies of the questions used in the original interview protocols and survey instruments for each region.

Southwest Interview Protocol

The interview is semi-structured and questions are open-ended to allow flexibility in interviewee responses. All responses will be kept strictly confidential and will only be used for the purpose of research. If permission is granted for the use of individual quotations, no specific attribution will be made to the source. The interview is anticipated to take approximately 35 to 60 minutes.

Interviewee Background & Organization Question (5 – 10 minutes)

1. Please tell me a little bit about yourself, your background and the organization where you work.

Critical Issues Question (5 – 10 minutes)

2. Please tell me about the critical issues or problems your organization faces regarding water resources management (i.e., water availability, regulations, finances, human/technical capacity, environmental, etc.).

General RISA and RISA Interaction Question (7 – 10 minutes)

3. Please tell me a little bit about your experiences interacting or collaborating with the Climate Impacts for the Southwest or other research organizations.

Climate Variability/Climate Change Question (7 - 10 minutes)

4. Can you tell me a little bit about how your organization is addressing climate variability and climate change and what facilitates or hinders your actions? Please provide examples.

Decision Making (5 – 10 minutes)

5. Can you please describe the process your organization uses to make decisions related to the critical issues you mentioned including what helps and what hinders this process?

Pacific Northwest Interview Protocol

The interview is semi-structured and questions are open-ended to allow flexibility in interviewee responses. All responses will be kept strictly confidential and will only be used for the purpose of research. If permission is granted for the use of individual quotations, no specific attribution will be made to the source. The interview is anticipated to take approximately 35 to 60 minutes.

Interviewee Background & Organization Question (5 – 10 minutes)

1. Please tell me a little bit about yourself, your background and the organization where you work.

Critical Issues Question (5 – 10 minutes)

2. Please tell me about the critical issues or problems your organization faces regarding water resources management (i.e., water availability, regulations, finances, human/technical capacity, environmental, etc.).

General RISA and RISA Interaction Question (7 – 10 minutes)

3. Please tell me a little bit about your experiences interacting or collaborating with the Climate Impacts Group or other research organizations.

Climate Variability/Climate Change Question (7 - 10 minutes)

4. Can you tell me a little bit about how your organization is addressing climate variability and climate change and what facilitates or hinders your actions? Please provide examples.

Decision Making (5 – 10 minutes)

5. Can you please describe the process your organization uses to make decisions related to the critical issues you mentioned including what helps and what hinders this process?

Southwest Survey Instrument Questions

Thank you very much for taking the time to complete this survey. Your participation in the Community Water System Survey is completely voluntary. We are committed to respecting your privacy and the privacy of your system. To ensure confidentiality, the information you provide, as well as any findings and materials from this study will not be associated with your name or your specific water system. If you represent a water provider that serves more than one community, we are asking you to complete the survey for the largest community that you serve, as identified at the top of the enclosed letter.

** Survey key #:*

C1. There are many issues that Community Water Systems face. Please select the three issues that are the most important to your system.

Aging infrastructure   Flooding   Regulation/compliance
Climate change   Groundwater depletion   Source water quality
Drinking water treatment   Growth   Training/human capacity
Drought   Lack of financial resources   Water rights/Additional water supply
Endangered species/In-stream flows   Land use planning   Other, _____

C2. We are interested in understanding information use, information needs, and how systems use information to manage risk. Please think about the following statements and mark 'yes' or 'no' for each question or, where applicable, mark the appropriate box or boxes.

A. We regularly attend conferences, workshops, training, or other events to stay current on new water management approaches and issues.

B. The past 100 year record of drought and precipitation is an appropriate indicator of future drought and precipitation events.

C. Severe flooding has been a concern for my water system over the past decade. If you answered NO, skip to D.

C.1. Flooding impacted my system's ability to deliver water during the last decade (check only one):

once twice three times or more.

D. More frequent severe drought or extreme precipitation events may make my system's water supply infrastructure or water treatment process less reliable.

E. My system uses real-time monitoring data or real-time monitoring technology to monitor source water quality and/or quantity.

F. My system uses forecasts such as those for precipitation, temperature, flooding, drought, reservoir levels, or other similar information to inform water system operation and management.

If you answered YES, skip to G on the next page.

F.1. We do not use forecasts or similar information because the information is (check all that apply):

not available for my system unreliable
too uncertain other, ____________________________

G. My system uses tree ring data or other precipitation/drought event proxies to inform water supply planning or management.

If you answered YES, skip to H.

G.1. We do not use tree ring or similar data because the information is (check all that apply):

not available for my system unreliable
too uncertain other, ____________________________

H. Climate change impacts on my water system are a concern.

I. Our water customers/users ask us to consider climate change impacts in our longer-term planning or management.

J. My system uses climate change scenarios or other climate change impacts information to inform longer-range water system planning or management.

If you answered YES, skip to K.

J.1. My system does not use climate change scenarios or other climate change impacts information because the information is (check all that apply):

not available for my system unreliable
too uncertain other, ____________________________

K. My system uses a water system model or other software to assist with daily water system operation and/or management. If you answered NO, skip to L.

K.1. We use climate forecasts or similar information in our water system model or other software to assist with daily water system operation and/or management.

L. My system uses numerical or other models to assist with longer-term water system planning. If you answered NO, skip to the next question, C3.

L.1. We use climate information in our numerical or other models to assist with longer-term water system planning.

C3. We would like to understand more about Community Water System information needs. In the space provided please indicate information you would like to have but cannot get.

____

____

C4. We are interested in learning where Community Water System supervisors/managers turn to for information. In Column [1] mark the boxes alongside the information sources you most often use to assist you with managing your system or for general information. In Column [2] mark the boxes alongside the information sources you most often use for weather or climate information (for example, precipitation, temperature, flooding, drought, reservoir levels, climate change, tree ring reconstructions, etc.). When indicating information sources, please consider the sources used within the last 5 years.

1. Climate Assessment for the Southwest (CLIMAS)
2. Federal Emergency Management Agency (FEMA)
3. National Integrated Drought Information System (NIDIS)
4. NOAA/National Weather Service

5. Southwest Climate Outlook
6. US Army Corps of Engineers
7. US Bureau of Reclamation
8. USDA/Natural Resources Conservation Service (NRCS)
9. US Environmental Protection Agency (EPA)
10. US Geological Survey (USGS)
11. Western Regional Climate Center
12. New Mexico Drought Monitor
13. New Mexico Environment Department, Drinking Water Bureau
14. New Mexico Office of the State Engineer
15. New Mexico State Climatologist
16. New Mexico State University and/or Cooperative Extension
17. University of New Mexico
18. American Water Works Association
19. Association of Metropolitan Water Agencies
20. New Mexico Municipal League
21. New Mexico Rural Water Association
22. Water Environment Federation
23. Commercial Weather or Climate Information Vendor
24. Engineer or other Consultant
25. News/Media

C5. Please list any other information sources you have used in the last 5 years not already marked in the spaces above:

____

____

C6. Understanding how often Community Water Systems collaborate with research or other organizations (i.e., universities, Extension offices, consulting engineers, research associations, etc.) is really important to us. How much do you collaborate with the following organizations?

		A lot	Some	A little bit	None	Never heard of organization
A.	Climate Assessment for the Southwest (CLIMAS)					
B.	New Mexico State University, Dept. __________________					
C.	The University of New Mexico, Dept.__________________					
D.	American Water Works Association					
E.	Water Research Federation					
F.	Engineering or other Consulting Firms					
G.	Other (please describe ____________________________)					

C7. How might research organizations better meet the needs of your water system?

____

____

Finally, please provide some basic information about your water system. Please mark the appropriate box, and where relevant, please give a response in the space provided.

D1. Water system ownership type:

Public Private Other, please describe:______________________

D2. Estimated daily water delivered, averaged over the last year:

________millions of gallons per day (MGD) or acre-ft per day (AFD)

D3. Estimated peak water delivered on a single day, over the last year:

________millions of gallons per day (MGD) or acre-ft per day (AFD)

D4. Do you meter your water?

Yes No

D5. Please list the three primary categories of water users within your system, with the main user listed first, followed by the second highest, and the third highest (for example, 1. residential, 2. agricultural, 3. wholesale, etc.):

1. _____________ 2. ____________ 3. ____________

D6. Does your water system provide water to other community water systems?

Yes No

D7. Does your water system purchase water from other community water systems?

Yes No

If you answered "Yes" to D6 or D7, please answer the following question. If you answered "No", skip to D9.

D8. Approximately how many systems are associated with the water you provide or purchase?

______# of other systems your system provides water to

______# of other systems your water is purchased from

D9. Approximate yearly total budget for your water system, including operation & maintenance, and planning:

<$25,000 $25,000-100,000 $100,000 -1 million

$1-10 million $10 -20 million >$20 million

D10. Including yourself, approximate number of staff who work for your water system:

Full-time: Part-time: Volunteer:

Pacific Northwest Survey Instrument Questions

Thank you very much for taking the time to complete this survey. Your participation in the Community Water System Survey is completely voluntary. We are committed to respecting your privacy and the privacy of your system. To ensure confidentiality, the information you provide, as well as any findings and materials from this study will not be associated with your name or your specific water system. If you represent a water provider that serves more than one community, we are asking you to complete the survey for the largest community that you serve, as identified at the top of the enclosed letter.

** Survey key #:*

C1. There are many issues that Community Water Systems face. Please select the three issues that are the most important to your system.

Aging infrastructure
Flooding
Regulation/compliance
Climate change
Groundwater depletion
Source water quality
Drinking water treatment
Growth
Training/human capacity
Drought
Lack of financial resources
Water rights/Additional water supply
Endangered species/In-stream flows
Land use planning
Other, _____

C2. Understanding information use, information needs, and how systems use information to manage risk is very important to improving the provision of relevant information. Please think about the following statements and mark 'yes' or 'no' for each question or, where applicable, mark the appropriate box or boxes.

A. We regularly attend conferences, workshops, training, or other events to stay current on new water management approaches and issues.

B. The past 100 year record of drought and precipitation is an appropriate indicator of future drought and precipitation events.

C. Severe drought has been a concern for my water system over the past twenty years. If you answered NO, skip to D. Otherwise, proceed to C.1.

C.1. My system has not had sufficient water supply to meet average daily water demands during the past twenty years:

once twice three times or more.

D. Severe flooding has been a concern for my water system over the past twenty years. If you answered NO, skip to E. Otherwise, proceed to D.1.

D.1. Flooding impacted my system's ability to deliver water during the past twenty years (check only one):

once twice three times or more.

E. More frequent severe drought or extreme precipitation events may make my system's water supply infrastructure or water treatment process less reliable.

F. My system has a drought preparation and response plan.

G. My system has a comprehensive, long-term water management plan.

H. My system uses real-time monitoring data or real-time monitoring technology to monitor source water quality and/or quantity.

I. My system uses forecasts such as those for precipitation, temperature, flooding, drought, reservoir levels, or other similar information to inform water system operation and management.

If you answered YES, skip to J on the next page. Otherwise, proceed to I.1 on the next page.

I.1. We do not use forecasts or similar information because the information is (check all that apply):

not available for my system unreliable

too uncertain other, ______________________________

J. My system uses tree ring data or other precipitation/drought event proxies to inform water supply planning or management.

If you answered YES, skip to K. Otherwise, proceed to J.1.

J.1. We do not use tree ring or similar data because the information is (check all that apply):

not available for my system unreliable

too uncertain other, ______________________________

K. Climate change impacts on my water system are a concern.

L. Our water customers/users ask us to consider climate change impacts in our longer-term planning or management.

M. My system uses climate change scenarios or other climate change impacts information to inform longer-range water system planning or management.

If you answered YES, skip to N. Otherwise, proceed to M.1.

M.1. My system does not use climate change scenarios or other climate change impacts information because the information is (check all that apply):

not available for my system unreliable
too uncertain other, ____________________________

N. My system uses a water system model or other software to assist with daily water system operation and/or management.

If you answered NO, skip to O. Otherwise, proceed to N.1.

N.1. We use climate forecasts or similar information in our water system model or other software to assist with daily water system operation and/or management.

O. My system uses numerical or other models to assist with longer-term water system planning.

If you answered NO, skip to the next question, C3. Otherwise, proceed to O.1.

O.1. We use climate information in our numerical or other models to assist with longer-term water system planning.

C3. I would like to understand more about Community Water System information needs. In the space provided please indicate information you would like to have but cannot get.

____

____

C4. Understanding how often Community Water Systems collaborate with research or other organizations (i.e., universities, Extension offices, consulting engineers, research associations, etc.) is also very important. How much do you collaborate with the following organizations?

	A lot	Some	A little bit	None	Never heard of organization
A. The Climate Impacts Group					

B. Washington State University, Dept.___________________

C. The University of Washington, Dept._________________

D. American Water Works Association

E. Water Research Foundation

F. Engineering or other Consulting Firms

G. Other (please describe ____________________________)

C5. How might research organizations better meet the needs of your water system?

____

____

C6. Community Water System supervisors/managers may obtain information from many sources. In Column [1] mark the boxes alongside the information sources you most often use to assist you with managing your system or for general information. In Column [2] mark the boxes alongside the information sources you most often use for weather or climate information (for example, precipitation, temperature, flooding, drought, reservoir levels, climate change, tree ring reconstructions, etc.). When indicating information sources, please consider the sources used within the last 5 years.

1. The Climate Impacts Group (CIG)
2. Federal Emergency Management Agency (FEMA)
3. International Research Institute for Climate Prediction
4. National Integrated Drought Information System (NIDIS)
5. NOAA/National Weather Service
6. Pacific Northwest National Laboratory
7. US Army Corps of Engineers
8. US Bureau of Reclamation
9. USDA/Natural Resources Conservation Service (NRCS)
10. US Environmental Protection Agency (EPA)
11. US Geological Survey (USGS)
12. Office of the Washington State Climatologist
13. State of Washington Water Research Center

14. Washington Department of Ecology
15. Washington Department of Fish and Wildlife
16. Washington Department of Health, Office of Drinking Water
17. Washington Department of Natural Resources
18. The University of Washington
19. Washington State University/University Extension
20. American Water Works Association
21. Washington Rural Water Association
22. Washington State Water Resources Association
23. Water Environment Federation
24. Engineer or other Consultant
25. Commercial Weather or Climate Information Vendor
26. News/Media

C7. Please list any other information sources you have used in the last 5 years not already marked in the spaces above:

____

____

C8. Please share what your water system has done in the past decade that you consider to be most innovative.

____

____

Finally, please provide some basic information about your water system. Please mark the appropriate box, and where relevant, please give a response in the space provided.

D1. Water system ownership type:

Public Private Other, please describe:_______________________

D2. Estimated daily water delivered, averaged over the last year:

________millions of gallons per day (MGD) or acre-ft per day (AFD)

D3. Estimated peak water delivered on a single day, over the last year:

________millions of gallons per day (MGD) or acre-ft per day (AFD)

D4. Do you meter your water?

Yes No

D5. Please list the three primary categories of water users within your system, with the main user listed first, followed by the second highest, and the third highest (for example, 1. residential, 2. agricultural, 3. wholesale, etc.):

1. _____________ 2. ____________ 3. ____________

D6. Does your water system provide water to other community water systems?

Yes No

D7. Does your water system purchase water from other community water systems?

Yes No

If you answered "Yes" to D6 or D7, please answer the following question. If you answered "No", skip to D9.

D8. Approximately how many systems are associated with the water you provide or purchase?

______# of other systems your system provides water to

______# of other systems your water is purchased from

D9. Approximate yearly total budget for your water system, including operation & maintenance, and planning:

<$25,000	$25,000-100,000	$100,000 -1 million
$1-10 million	$10 -20 million	>$20 million

D10. Including yourself, approximate number of staff who work for your water system:

Full-time: Part-time: Volunteer:

Appendix 2: Representativeness of Survey Respondents

The survey attempted to capture the diversity among water managers in the Pacific Northwest (PNW) and Southwest (SW). The survey, administered to 2,645 water managers at Community Water Systems across the PNW and SW, resulted in 667 completed surveys for an overall response rate of 25%. Response rates from the PNW were higher than response rates from the SW. Response rates are summarized in Table A2.1.

Table A2.1 Interview and survey response rates by region.

Data Collection Method	Southwest			Pacific Northwest		
	Respondents	Non-respondents	Resp. Rate (%)	Respondents	Non-respondents	Resp. Rate%
Interviews	22	4	84.6	16	3	84.2
Surveys	131	752	14.8	536	1226	30.4

A state-by-state analysis of survey respondents versus non-respondents was conducted to assess representativeness. The analysis was conducted using two variables available for both respondents and non-respondents: *population served*, an indicator of system size, and *primary water source*, an indicator of reliance on groundwater or surface water. The calculation required the creation of new data sets for the population of water managers surveyed and the creation of a new variable *respondent* with values of "1" for respondent and "0" for non-respondent to facilitate the comparison of respondents versus non-respondents for the two variables: *population served* and *primary water source*.

The procedure for *population served* involved testing the null hypothesis that the population of non-respondents equaled the population of respondents using the Kolmogorov-Smirnov Test (K-S Test), which makes no assumption about the distribution of the data and tests the differences in the shapes of the cumulative distributions of respondents and non-respondents. The K-S Test was selected because *population served* was non-parametric. A histogram of the data for *population served* indicated the distribution was skewed positively due to the abundance of small systems concentrated on the left when population served was graphed from low to high along the x-axis. For the K-S Tests, Z scores of less than 1.96 indicate the two samples (respondents only vs. non-respondents only) came from the same underlying distribution, at the p=.05 significance level. Results from the analysis of *population served* for the surveyed population as a whole and by state are presented in Table A2.2.

Table A2.2 K-S Test of *population served* for respondents and non-respondents.

	Kolmogorov-Smirnov Test	
State	*z*-score	*p*-value
All States (Arizona, Idaho, New Mexico, Oregon, and Washington)	1.457	0.029
Arizona	1.179	0.124
Idaho	0.581	0.889
New Mexico	1.033	0.236
Oregon	1.573	0.014
Washington	0.840	0.480

Because the Z-scores for each state and as a whole were less than 1.96, we cannot reject the null hypothesis. Results indicate that survey respondents did not differ significantly from non-respondents in terms of the mean population served.

The procedure for *primary water source* required a chi-square test to determine whether or not the proportion of systems using primarily surface water were the same for both respondents and non-respondents. The null hypothesis was rejected if the *p*-value was less than or equal to 0.05 meaning the proportions of systems using groundwater and surface water in the two groups were different. Results from the analysis of *primary water source* for the surveyed population as a whole and by state are presented in Table A2.3.

Table A2.3 Test of *primary water source* for respondents and non-respondents.

State	χ^2 Test Test Statistic	 *p*-value
All States (Arizona, Idaho, New Mexico, Oregon, and Washington)	22.104	0.000
Arizona	4.825	0.090
Idaho	1.109	0.574
New Mexico	10.395	0.006
Oregon	4.540	0.103
Washington	6.072	0.048

Results indicate we cannot reject the null hypothesis for Arizona, Idaho, and Oregon because the p-values for these states are greater than 0.05. So, for these states, the fraction of respondents relying on surface water is not statistically different than the fraction of non-respondents relying on surface water. However, this similarity between respondents and non-respondents does not hold for New Mexico and Washington or when looking at the states as a whole. In these cases, we must reject the null hypothesis that respondents and non-respondents rely on surface water at about the same rate. This indicates respondents are not representative of non-respondents in terms of *primary water source.*

The analysis of characteristics of the respondents versus non-respondents showed both similarities and differences between the two groups. First, the null hypothesis that the population served by non-respondents equaled the population served by respondents was not rejected based on results from the Kolmogorov-Smirnov Test. This suggested the mean *population served* did not differ significantly between respondents and non-respondents. On the other hand, results from the chi-square test for *primary water source* showed that the proportion of surface water systems among respondents compared to the proportion of surface water systems among non-respondents were not equal. The state-by-state chi-square indicated the inequality of proportions between non-respondents and respondents stemmed primarily from differences in New Mexico and Washington where slightly more surface water systems responded. The combined states chi-square shows that proportionally more surface water systems responded to the survey than groundwater systems. This difference in responsiveness between surface and groundwater systems is expected given groundwater systems dominate the population of water managers as a whole (2,146 groundwater systems vs. 268 surface water systems). Hence, if even a few surface water systems respond, many more groundwater systems would need to respond to compensate proportionally. But groundwater systems tend to be much smaller which we see by comparing the average population served by groundwater systems to that served by surface water systems. The average population served for a groundwater system is 3,476 while the average population served of surface water systems is 24,340. Because groundwater systems are smaller, they tend to operate with fewer, often unpaid staff. Having fewer and mostly volunteer staff makes it more difficult for these systems to find the time and resources to participate in a research survey. Groundwater system response rates may also be lower for reasons other than system size and staffing. For example, groundwater systems may be less interested in responding to a survey they interpret to be focused on climate variability and change. Research has shown water managers at groundwater systems perceive their systems to be less vulnerable to climate impacts (O'Connor et al. 2005). Write-in responses on a number of surveys by water managers from groundwater systems confirm this perception among some respondents surveyed. Of course, these systems participated in spite of this perceived lower risk!

The question that remains is do the results from this analysis of representativeness mean for the generalizeability of the results? First, what does the difference in proportion of respondents using surface water sources versus groundwater sources mean for generalizability? If water source is an important predictor of information use as some research indicates (Yarnal et al. 2006), then weighting of surface water systems relative to groundwater systems might be important. For this study, *primary water source* was not a significant predictor of RISA use among non-stakeholders in either bivariate or multivariate analyses. Rather, *population served* (i.e., system size) was an important predictor in both bivariate and multivariate analyses. This difference in predictive importance between population served and water source means having a representative sample in terms of mean system size is relatively more important than having a representative sample in terms of proportion of systems using groundwater and surface water. Overall, the analysis of representativeness indicates respondents are generally representative of non-respondents in terms of population served (i.e., an indicator of system size).

Appendix 3: Logistic Regression

To understand the relative importance of the various predictors of RISA information use we must conduct a multivariate analysis – in this case a binary logistic regression. Before a model could be developed, we first had to test possible correlations or associations between the independent variables targeted for inclusion in the model. Number of connections and total yearly budget were highly correlated with population ($r = 0.95$, $p < .001$ and $r_s = 0.88$, $p < .001$). Therefore, only population was included in the model as an indicator of water system size. Results from the bivariate tests of association are presented in Table A3.1 and Table A3.2. The latter contains the results of bivariate tests of association between the independent variables in the final regional models for CIG use and CLIMAS use, respectively.

Table A3.1 Tests of association for independent variables in model of RISA Use

	RISA Use					
	lnPop-ulation	Water Source	Exp. Drought	Endg Spec/ IS Flows	Distance (miles)	Info. Seeking
lnPopulation						
Water Source	62.1***^{a}					
Experience Drought	0.04^b	0.03^c				
Endg.Spec/ISFlows	0.13***^{b}	0.09*^{c}	0.001^d			
Distance (miles)	-0.12**^{b}	5.91**^{a}	0.13**^{b}	-0.05^b		
Information Seeking	0.38***^{b}	10.4***^{a}	0.11**^{b}	0.04^b	0.003^b	
Collaboration	0.28***^{b}	0.15***^{c}	0.04^d	0.08^d	0.013^b	0.38***^{b}

*Significant at 0.05, two-tailed test.
**Significant at 0.01, two-tailed test.
***Significant at 0.001, two-tailed test.
^{a} Cell entry is F statistic from Analysis of Variance.
^{b} Cell entry is Pearson Correlation coefficient, *r*.
^{c} Cell entry is Cramer's V.
^{d} Cell entry is Phi, Φ.

Table A3.2 Tests of association for independent variables in regional models

	Pacific Northwest					
	lnPopulation	Water Source	Exp. Drought	Endg Spec/ IS Flows	Distance (miles)	Information Seeking
lnPopulation						
Water Source	61.26***[a]					
Experience Drought	0.13**[b]	0.11*[c]				
Endg.Spec/ISFlows	0.16***[b]	0.11*[c]	0.03[d]			
Distance (miles)	-0.11*[b]	4.83**[a]	0.08[b]	-0.05[b]		
Information Seeking	0.44**[b]	17.21***[a]	0.18***[b]	0.06[b]	0.02[b]	
Collaboration	0.27***[b]	0.19***[c]	0.05[d]	0.08[d]	0.05[b]	0.42***[b]
	Southwest					
	lnPopulation	Water Source	Use Proxies	Information Seeking	Distance (miles)	
lnPopulation						
Water Source	14.72***[a]					
Use Proxies	0.36***[b]	0.06[c]				
Information Seeking	0.25**[b]	0.07[c]	0.09[b]			
Distance (miles)	-0.28**[b]	0.08[a]	-0.14[b]	-0.06[b]		
Collaboration	0.40***[b]	0.13[c]	0.28**[d]	0.27**[b]	-0.26**[b]	

*Significant at 0.05, two-tailed test.
**Significant at 0.01, two-tailed test.
***Significant at 0.001, two-tailed test.
[a] Cell entry is F statistic from Analysis of Variance.
[b] Cell entry is Pearson Correlation coefficient, *r*.
[c] Cell entry is Cramer's V.
[d] Cell entry is Phi, Φ.

The tests of association indicated a number of statistically significant relationships between independent variables, but significance was less important than the value of the correlation coefficient. The strongest correlations are less than the 0.5 level which reflects at most a moderate correlation. None of the correlation coefficients or other test statistics was large enough to pose a multicollinearity problem in the multivariate analysis for the variables that remained in the model. As such, no other independent variables were eliminated from the regression analysis. Once variable selection and tests of association were complete, model development was begun. Because a few regional differences emerged from preliminary analysis of the interview data, three models were developed one for overall RISA use and two others for CIG use and CLIMAS use to capture regional differences. The data for the CIG use model supports a larger number of independent variables than the CLIMAS use model because the SW data set contains a lower number of RISA users, the dependent variable.

Table A3.3 presents the result of the regression model for RISA use and Table A3.4 contains results from the two regional regression models for CIG use and CLIMAS use, respectively. All models control for system size, using the natural log of population served (*lnPopulation*) as a proxy, and *primary water source*. This facilitates the ability to understand the relative importance of the independent variables distance (accessibility of expertise), information seeking, collaboration, concern for endangered species/instream flows, experience drought, and use of climate proxies at predicting RISA controlling for system size and water source. Primary water source was included as a control variable because source of supply has been previously identified as an important predictor of climate information use (O'Connor et al. 2005; Yarnal et al. 2006). The analytic strategy depicted in all tables is:

1. First, to regress the measure of *RISA Use, CIG Use,* or *CLIMAS Use* on water system attributes – system size (*lnPopulation*) and water source.
2. Second, to sequentially add or remove variables until a final model is reached. For example, in the second equation in Table A3.3 (i.e., column 3-2) *primary water source* drops out of the model due to lack of significance.
3. The last equation – (7) for RISA use, (6P) for the PNW, and (5S) for the SW - is the fully developed model with statistically significant variables present. However, in the PNW equation (6P) *lnpopulation* drops out of the final model due to lack of significance.

Table A3.3 Regression model for RISA Use.

RISA Use regressed on water source, natural log population served, collaboration, information sources, distance, use of proxies, endangered species/instream flows, and drought

	3-1	3-2	3-3	3-4	3-5	3-6	3-7
Primary Water Source	-0.214						
lnPopulation	0.50***	0.39***	0.34***	0.27**	0.24*	0.26**	0.22*
Collaboration		1.84***	1.34***	1.64***	1.59***	1.60***	1.72***
Information Seeking			0.04***	0.04***	0.04***	0.04***	0.04***
Distance (miles)				-0.01***	-0.01***	-0.01***	-0.01***
Use Proxies					1.09		
Endg. Spec. / IS Flows						1.61*	1.73*
Experience Drought							1.73***
N	660	622	622	622	606	622	610
Nagelkerke R^2	0.16	0.26	0.35	0.42	0.42	0.43	0.48
H&L	0.84	0.57	0.82	0.22	0.26	0.20	0.25
Model Chi-square	4.15	6.68	4.41	10.63	10.13	11.00	10.18
-2 Log likelihood	280.50	235.80	212.70	192.27	187.64	188.52	171.19

* Significant at 0.05, two-tailed test.

** Significant at 0.01, two-tailed test.

*** Significant at 0.001, two-tailed test.

Cell entries for individual variables are calculated regression coefficients (β).

Equation 3-1 in the RISA Use model shows that water source is negatively associated with RISA use and is not statistically significant. While the odds of RISA use are lower among groundwater systems, as indicated by the negative sign in front of the coefficient and variable coding (i.e., groundwater coded as 1, surface water as 2, and groundwater used as reference category), *primary water source* is not significant in the model. The lack of significance means water source does not predict RISA use when holding the other independent variables constant. This is true for the variable *primary water source* in all three models. In Equation 3-1 the variable *lnPopulation* is positive and significant. According to this equation, the odds of using RISAs increase for larger systems. However, the effect size, indicated by the size of the coefficient and the significance of the variable, becomes smaller as more variables are added to the model. While *lnpopulation* remains important in the overall RISA use model, the variable loses significance in the regional models. Altogether this indicates *lnPopulation* is not as strong of a predictor of RISA use as other independent variables with larger effect sizes; higher levels of significance; and/or more stability in the coefficient.

Dropping water source and adding collaboration to Equation 3-2 increases explained variance from 16% to 26%, a sizeable increase. The odds of using a RISA increase among water managers that collaborate with universities. Equation 3-3 shows the results of adding information sources further increasing the explained variance from 26% to 35%. Water managers that seek a wide range information sources have greater odds of using RISAs. A significant negative association is seen when distance is added in Equation 3-4 increasing explained variance to 42%. Water managers at systems that are located further away from the RISAs have lower odds of using RISAs. Adding use of proxies to the model in Equation 3-5 results in no increase in explained variance. Concern for endangered species/instream flows is added in Equation 3-6 increasing explained variance slightly from 42% to 43%. Lastly, adding drought to Equation 3-7 again shows a positive, statistical relationship between systems that experience drought and RISA use and increases the explained variance from 43% to 48%.

The final model reveals some consistency between drivers important in the much smaller, non-random sample of interviewees and those that appear to predict RISA use among the larger population of water managers in the PNW and SW. The equation for the final model which achieves an explained variance of 48% is included as Equation 1. The detailed model including the standard error, p-value, odds ratio, and 95% confidence interval for each variable is shown in Table A3.5.

$$\text{Predicted logit of (RISA Use)} = -5.99 + (0.22)*\text{LNPOPULATION} + (1.72)*\text{COLLABORATION} + (0.04)*\text{INFORMATION SOURCES} + (-0.01)*\text{DISTANCE} + (1.73)*\text{ENDANGERED SPECIES} + (1.73)*\text{DROUGHT} \qquad \text{EQ(1)}$$

Table A3.4 Regression models for regions showing CIG use and CLIMAS use, respectively.

Pacific Northwest: CIG use regressed on water source, natural log population served, distance, collaboration, information sources, endangered species/instream flows, and drought

	4-1P	4-2P	4-3P	4-4P	4-5P	4-6P
Primary Water Source	-0.036					
lnPopulation	0.57***	0.53***	0.41***	0.34**	0.33*	0.22
Distance (miles)		-0.01**	-0.01***	-0.01***	-0.01***	-0.01***
Collaboration			2.64***	2.26***	2.17***	2.27***
Information Seeking				0.06***	0.06***	0.06***
Endg. Spec/ IS Flows					1.89*	1.94*
Experience Drought						1.43*
N	532	532	507	507	507	495
Nagelkerke R^2	0.20	0.24	0.39	0.51	0.53	0.55
Hosmer & Lemeshow	0.29	0.11	0.05	0.99	0.99	0.85
Model Chi-square	9.67	13.05	15.25	1.13	1.67	4.04
-2 Log likelihood	183.06	174.49	142.60	116.88	112.70	104.44

Southwest: CLIMAS use regressed on water source, natural log population served, collaboration, use of proxies, and information sources

	4-1S	4-2S	4-3S	4-4S	4-5S
Primary Water Source	-0.63				
lnPopulation	0.39**	0.28			
Collaboration		1.18			
Use Proxies			2.02*	1.85*	1.68*
Information Seeking				0.02*	0.02*
Distance (miles)					-0.01*
N	128	115	117	117	117
Nagelkerke R^2	0.12	0.18	0.07	0.07	0.24
Hosmer & Lemeshow	0.64	0.52	0.00	0.34	0.76
Model Chi-square	6.04	7.18	0.00	7.88	4.94
-2 Log likelihood	88.17	70.50	88.49	83.57	76.91

* Significant at 0.05, two-tailed test.
** Significant at 0.01, two-tailed test.
*** Significant at 0.001, two-tailed test.
Cell entries for individual variables are calculated regression coefficients (β).

Equation 4-1P in the PNW model shown in the top portion of Table A3.4 and Equation 4-1S in the SW model shown in the bottom portion of Table A3.4 indicates *primary water source* is negatively associated with *CIG Use* and *CLIMAS Use* and that water source is again not statistically significant. This relationship is consistent with that in the overall RISA Use model. The variable *lnPopulation* also exhibits a similar pattern of decreasing effect size and reduced statistical significance through model development in both regional models of RISA use as seen in the overall model of RISA use. However, system size has the least predictive capacity in the SW model of CLIMAS use since *lnPopulation* loses significance in Equation 4-2S when collaboration is added compared to 4-6P in the PNW.

Generally, the regional RISA use models exhibit similar relationships between the dependent and independent variables when variables are added to both the PNW regional model and the SW regional model. However, the SW model is not as robust as the PNW model due to the low occurrence of y=1 and lower overall sample size. These restrictions limit explanatory power and the ability to test multiple independent variables that might help explain CLIMAS use. The regional specific CIG Use model in Table A3.4 resembles the overall RISA Use model depicted in Table A3.3. The main difference is that the final CIG Use model does not include the variable *lnpopulation*. However, even without this additional variable, the final CIG use model shown in Equation 4-7P in Table A3.4 achieves a better percent explained variance than the overall RISA Use model shown in Table A3.3 (55% vs. 48%).

The CLIMAS Use model also shares similarities with the overall RISA Use model. Equation 4-2S depicts the effect of adding *collaboration* to the CLIMAS Use model. Adding *collaboration* increases explained variance from 12% to 18%. However, neither variable is significant. *Use Proxies* is added to the SW model in Equation 4-3S exhibiting a significant, positive association with use of CLIMAS explaining 7% of the variance. Adding *information sources* to Equation 4-4S does not improve the explained variance though both variables are significant. Adding the variable *distance* to the CLIMAS Use model in Equation 4-5S increases explained variance to 24% in the final CLIMAS Use model with *use proxies, information sources,* and *distance.* The final regression equations for CIG Use and CLIMAS Use, shown in Table A3.4 as Equations 4-6P and 4-5S, respectively, are detailed in Table A3.5. The table includes the standard error, p-value, odds ratio, and 95% confidence interval for each variable in each final regional model and for the overall RISA Use model. The final CIG Use and CLIMAS Use logistic regression equations are shown below as Equation 2 and Equation 3, respectively.

Predicted logit of (CIG Use) = -5.215 + (-0.01)*DISTANCE + (2.27)*COLLABORATION + (0.06)* INFORMATION SOURCES + (1.94)*ENDANGERED SPECIES + (1.43)*DROUGHT EQ(2)

Predicted logit of (CLIMAS Use) = -1.56 + (1.68)*USE PROXIES + (0.02)*INFORMATION SOURCES + (-0.01)*DISTANCE EQ(3)

Table A3.5 Final Regression Models with Log Odds, Standard Errors, and Confidence Intervals

Overall RISA use regressed on natural log population served, collaboration, information sources, distance, use of proxies, endangered species/instream flows, and drought

	Final Model RISA Use				
	Coeff.	Std. Error	p-value	Exp(β)	95% C.I.
lnPopulation	0.219	0.098	0.025	1.25	(1.03, 1.51)
Collaboration	1.718	0.456	0.000	5.57	(2.28, 13.6)
Information Seeking	0.044	0.009	0.000	1.05	(1.03, 1.06)
Distance (miles)	-0.009	0.002	0.000	0.99	(0.98, 0.99)
ES / IS Flows	1.730	0.846	0.041	5.64	(1.01, 29.6)
Experience Drought	1.729	0.456	0.000	5.64	(2.31, 13.8)
Constant	-5.991				

Pacific Northwest: CIG use regressed on natural log population served, distance, collaboration, information sources, endangered species/instream flows, and drought

	Final Model CIG Use				
	Coeff.	Std. Error	p-value	Exp(β)	95% C.I.
Distance (miles)	-0.013	0.003	0.000	0.99	(0.98, 0.99)
Collaboration	2.272	0.615	0.000	9.70	(2.91, 32.4)
Information Seeking	0.060	0.012	0.000	1.06	(1.04, 1.09)
Endg. Spec/ IS Flows	1.937	0.920	0.035	6.94	(1.14, 42.1)
Experience Drought	1.429	0.650	0.028	4.17	(1.17, 14.9)
Constant	-5.215				

Southwest: CLIMAS use regressed on collaboration, use of proxies, and information sources

	Final Model CLIMAS Use				
	Coeff.	Std. Error	p-value	Exp(β)	95% C.I.
Distance (miles)	-0.006	0.002	0.017	0.99	(0.98, 0.99)
Use Proxies	1.68	0.937	0.050	5.36	(0.85, 33.6)
Information Seeking	0.022	0.009	0.019	1.02	(1.01, 1.04)
Constant	-1.563				

* Significant at 0.05, two-tailed test.
** Significant at 0.01, two-tailed test.
*** Significant at 0.001, two-tailed test.

Examining the odds ratios and confidence intervals reported in Table A3.5 permits an examination of the strength of associations between predictors and RISA use. Variables with the highest odds ratios (i.e., Exp(β)) have the strongest effect on RISA use. However, care must be exercised when interpreting the relative value of the odds ratio depending on the nature of the type of independent variable, the unit of measure, and the magnitude of the odds ratio. Continuous measures are more challenging to interpret than binary, dichotomous variables made more so in these models because the units for each continuous measure are different. For example, population served is a natural log of population, information sources is a percent, and finally, length is measured in miles. One approach is to simply examine what happens to the logit of Y when there is a one unit increase in the continuous variable. Consider for example, the results for the logistic regression of overall RISA use shown in the top of Table A3.5. In this model, the odds ratio for the continuous independent variable *lnpopulation* is interpreted to mean for every one unit increase in the natural log of population served, the odds of RISA Use increase by 25 percent. Because the odds ratio is a point estimate or the middle value in the 95 percent confidence interval, the actual odds of increased RISA use are between 3% and 51%. Still, a better understanding of the impact of a one unit increase in the natural log of population on RISA use can be seen if the population increase is associated with a representative value. For example, according to the odds ratio for *lnPopulation* a difference in population served between a system that serves 10,100 and one that serves 100 yields an increase in the odds of RISA Use by two and a half times. But the effect of population size on RISA Use varies along the slope of the logit curve. For example, the same difference in population of 10,000 between systems serving 110,000 compared to one serving 100,000 does not have the same effect on RISA Use. On the other hand, comparing a system serving 10 million people with one serving 100,000 people and the increase in population served again results in an increase in the odds of RISA use by two and a half times.

Interpreting the odds ratio for *information sources* and *distance*, two other continuous variables, follows a similar approach to that used to interpret *lnpopulation*. For every one unit increase in *information sources*, the odds of RISA use increase by 5 percent. To better understand what it means for a one unit increase in *information sources* consider the effect of a 17% increase in the amount of information sources used by one water system manager over another. This difference in amount of information sources results in an increase in the odds of RISA use by two times. Lastly, for every one unit increase in *distance*, the odds of using a RISA decrease by 1 percent. To better understand the effect of a one unit increase of distance on reducing the odds of RISA use consider two systems one of which is located 50 straight line miles further away from a RISA. The additional distance decreases the odds of using a RISA by 36 percent.

Interpreting dichotomous categorical independent variables is more straightforward and allows for comparing the relative effect of each independent variable on the dependent variable. *Collaboration*, *use proxies*, *endangered species/instream flows*, and *drought* are all dichotomous categorical variables in the RISA Use model. Examining the odds ratios for these variables enables a relative comparison of the strength of effect on the dependent variable *RISA Use*. *Endangered species/instream flows* and *drought* have slightly larger effects on RISA Use than *collaboration*. However, there is more confidence in the value of the effects of *collaboration* and *drought* on RISA Use indicated by the narrower confidence intervals and smaller relative standard errors in comparison to *endangered species/instream flows*. Starting with *drought* or *endangered species/instream flows*, systems that experience drought or that have concerns for endangered species or instream flows are 5.6 times more likely to use a RISA. Water managers that collaborate with universities are 5.6 times more likely to use a RISA. All of the variables in the model are significant ranging from $p<.001$ for *collaboration*, *information sources*, and *drought* to $p<.05$ for *lnpopulation* and *endangered species/instream flows*.

The variables in the final models for CIG Use and CLIMAS Use can be interpreted in the same manner as the variables in the overall model for RISA Use. Increasing distance has the same negative association with CIG Use though actually a larger negative effect than both the overall RISA use and CLIMAS use models. Increasing population is more important in the overall RISA Use model than either regional model. For information sources, there is a slightly greater association with the odds of increased CIG use and a smaller association with odds of increased CLIMAS use when compared to the overall RISA use model. The use of proxies has a much greater positive association with increased odds of CLIMAS use than any other model. However, the coefficient is less precise as indicated by the large standard error (0.937) and large confidence interval.

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