STAKEHOLDER DRIVEN RESEARCH IN A HYDROCLIMATIC CONTEXT

By

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DEDICATION

This work is dedicated to my parents, *Robert and Joyce Hartmann*, who instilled in me a love of learning and the confidence to pursue just about anything.

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ABSTRACT

Stakeholder driven research has been advocated to link hydroclimatic research with the needs and capabilities of groups affected by climatic variability and related governmental policies. A stakeholder driven research agenda was designed, focusing on hydroclimatic forecasts and their assessment, within the context of an interdisciplinary integrated assessment of the vulnerability of diverse stakeholders to climate variability in the U.S. Southwest.

Water management, ranching, and wildland fire management stakeholders were solicited for their input. Their perspectives about hydroclimatic variability and opportunities for using hydroclimatic forecasts differed widely. Many individuals were uninformed or had mistaken impressions about seasonal hydroclimatic forecasts, but understood practical differences between forecasts for "normal" conditions and "non-forecasts" having total uncertainty. Uncertainty about the accuracy of forecasts precludes their more effective use, as does difficulty in distinguishing between "good" and "bad" information.

A survey of hydroclimatic forecasting confirmed stakeholder perceptions and identified improvements in hydrologic predictability that could be rapidly incorporated into current operations. Users faced a complex and evolving mix of forecasts available from many sources, but few corresponding interpretive materials or reviews of past performance. Contrasts between the state of meteorologic and hydrologic forecasting were notable, especially in the former's greater operational flexibility and more rapid incorporation of new observations and research products.

The research agenda uses predictions as the linkage between stakeholders and scientific advances in observations (e.g., snow conditions) or process understanding. The agenda focuses on two areas: (1) incremental improvement of seasonal water supply forecasts, and (2) improvement of stakeholder perceptions of forecasts through ongoing forecast assessments. A forecast evaluation framework was developed that provides consistency in assessing different forecast products, in ways that that allow individuals to access results at the level they are capable of understanding, while offering opportunity for shifting to more sophisticated criteria.

Using the framework, seasonal temperature and precipitation outlooks issued by the National Weather Service were evaluated, considering regions, lead times, seasons, and criteria relevant to different stakeholders. Evaluations that reflect specific user perspectives provide different assessments of forecast performance. Frequently updated, targeted forecast evaluations should be available to potential users.

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

Hydroclimatic research is, in large part, funded by society through taxes paid to federal and state governments. The implicit assumption behind this arrangement between science and society has been that improvements in understanding would inevitably lead to societal benefits (Stokes, 1997). However, in recent years, governments have been more explicit in their expectations that investments in scientific research should have value to society, including hydroclimatic research (Byerly and Pielke, 1995; Dunne, 1998). For example, Congressional legislation establishing the United States Global Change Research Program (P.L. 101-606) explicitly called for the program to "produce useable science". However, there has been disappointment in extent to which improvements in hydroclimatic science from large-scale research programs have affected resource management policies and practices (Pielke, 1995, 2001; National Research Council, 1998a,b; Kates et al., 2001).

Calls have been made for research to become user-inspired or "stakeholder driven" (Changnon, 1986; Breen et al., 1995; Stokes, 1997). Stakeholders are individuals or groups that have interests affected by conditions and activities within a region, or that have the ability to affect regional conditions and activities (Phillips, 1997; Mitchell, 1997). Integrated assessments have been advocated as one interdisciplinary approach to better understand how elements of society are affected by natural processes (e.g., hydroclimatic variability and change), and to subsequently inform the conduct of earth science research so as to produce useable science (Subcommittee on Global Change Research, 1997). While a broad range of hydroclimatic researchers agree on the need for sustained direct interaction between scientists and decision makers as a way to ensure scientific results have applicability, there is little experience with or agreement about what comprises successful stakeholder driven research.

This dissertation describes several distinct research efforts leading to the development of a stakeholder driven hydroclimatic research, in the context of the Climate Assessment for the Southwest (CLIMAS) project. CLIMAS is funded by the National Oceanic and Atmospheric Administration (NOAA) and is one of five NOAA Regional Integrated Science and Assessment (RISA) projects. Each project is aimed at improving their region's ability to effectively respond to climate variability and changes, through scientific research and communication about climate and its impacts on a broad range of human activities (Pulwarty, 2001a). The work presented here is comprised of (1) extensive iterative interactions with diverse stakeholders, and (2) a review of the current state of hydroclimatic forecasting for the Southwest. From those foundations, a scientific research agenda is proposed to accommodate stakeholder input. Research on one element of the agenda is presented, consisting of the development and application of a framework for evaluating hydroclimatic forecasts from perspectives meaningful to stakeholders.

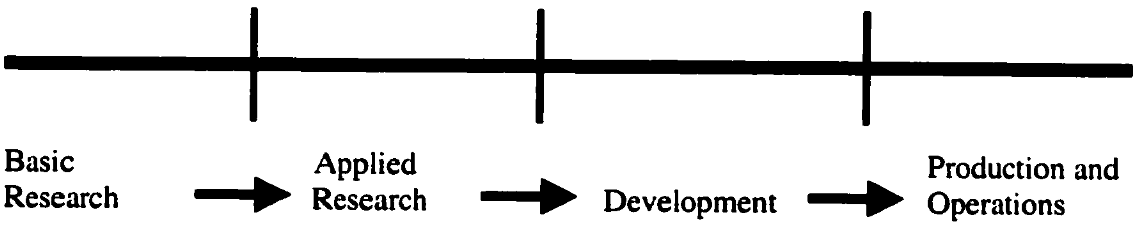
1.2 BACKGROUND

1.2.1 Science and Society

Until recently, federal funding priorities for scientific research were founded on perspectives about basic and applied research developed near the end of World War II (Stokes, 1997). Those perspectives held that basic and applied research were fundamentally different (Bush, 1945). Further, the quest for scientific understanding and application of knowledge were seen as incompatible. In the words of Bush (1945), "applied research invariably drives out pure [research]". Linkages between basic and applied research were made through a linear model (Figure 1.1), which considered basic research as the fundamental source for technological innovation and societal benefits. Societal benefits were also seen as an inevitable outcome of basic research (Bush, 1945; Stokes, 1997).

Paradoxes exist in the relationship between basic and applied research in many fields (including hydrology and meteorology), but the linear model dominated decisions about scientific funding priorities until relatively recently (Byerly and Pielke, 1995; Stokes, 1997). In hydrology, the case has been made for more distinct separation of hydrologic science from hydrologic applications or engineering (Klemes, 1988; National Research Council, 1991). However, growing skepticism about the inevitability of societal benefits from investments in scientific research has led to a reexamination of relationships between basic and applied research and society, which ultimately is both benefactor and beneficiary of research investments (Pielke and Byerly, 1998).

Figure 1.1. Linear model of scientific research and society (from Stokes [1997], based on Bush [1945]).



Stokes (1997) posed two alternative models for the relationship between basic and applied research and society. The static model (Figure 1.2) makes a case for the compatibility of seeking to both increase scientific understanding and produce usable science, through user-oriented basic research. The dynamic model (Figure 1.3) recognizes interdependencies between scientific understanding and technological capabilities. For example, much of the recent surge in basic hydroclimatic research has been enabled by improvements in computational and remote sensing technologies (Earth Systems Science Committee, 1988). The dynamic model also makes clear that technological improvements can be a direct consequence of basic research, if the research also accommodates user needs. However, the translation of either the static or dynamic models into practice, through the structuring of scientific research agendas, remains a challenge, including for hydroclimatic research (Pielke and Glantz, 1995; Dunne, 1998; Burges, 1998).

1.2.2 The CLIMAS Project

The CLIMAS project was created to "undertake research on the nature, causes, and consequences of climate change and variability in the Southwestern United States with the goal of providing improved information to regional decisionmakers and resource managers" (Bales et al., 1997). The CLIMAS project began with four key aims for its research: that it be integrative, interdisciplinary, participatory, and iterative. Toward those ends, three types of integration were planned: (1) integration of researchers and stakeholders, (2) disciplinary integration of CLIMAS researchers, and (3) end-to-end

Figure 1.2. Quadrant model of scientific research and society (from Stokes, 1997).

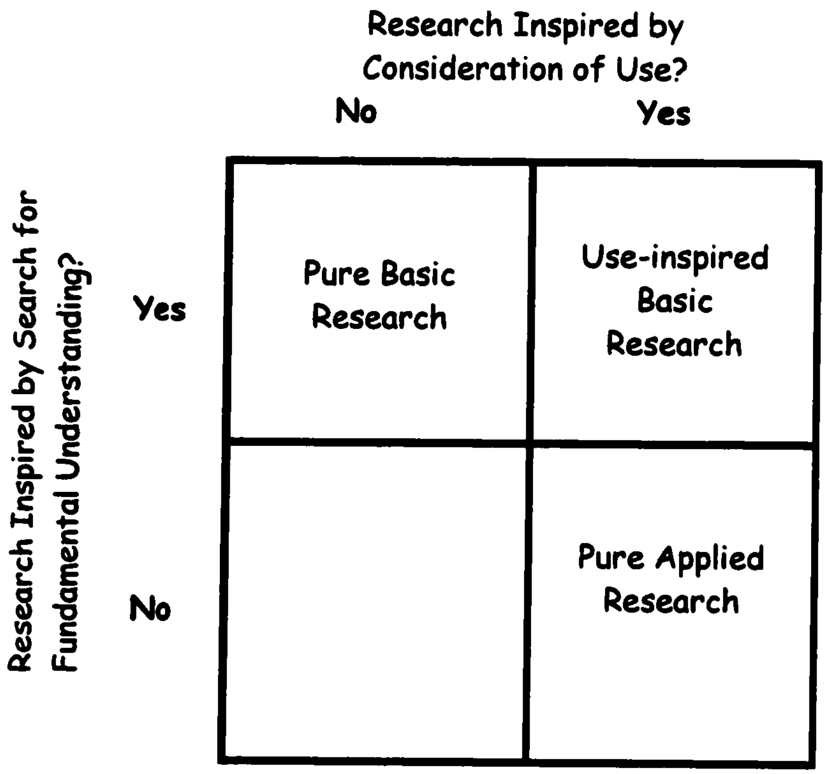
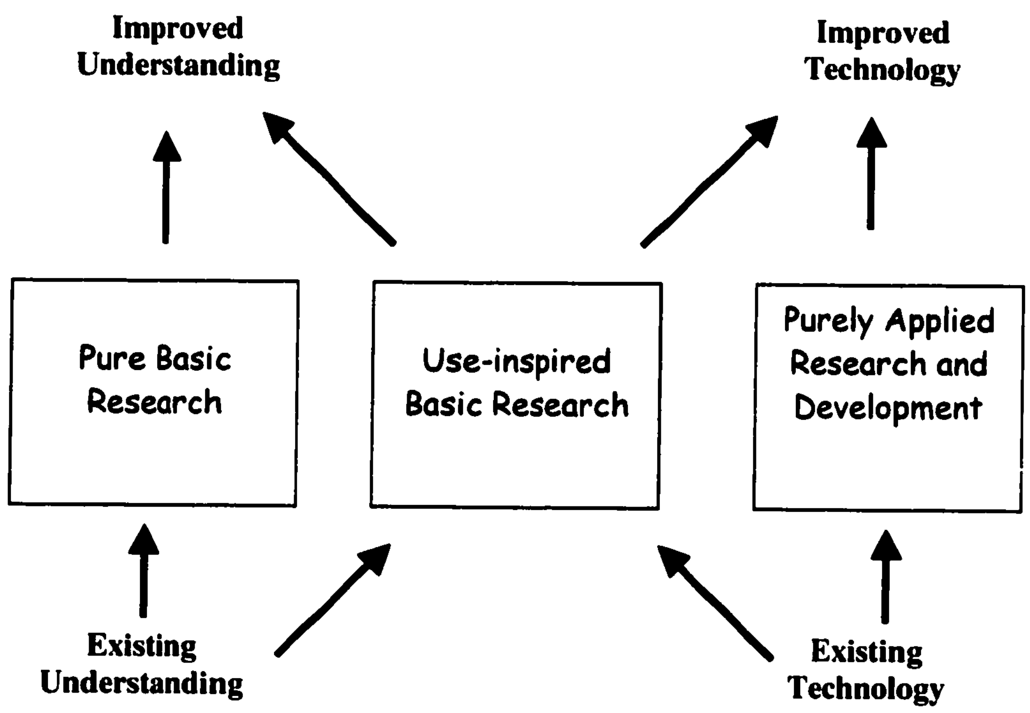


Figure 1.3. Dynamic model of scientific research and society (from Stokes, 1997).



integration of research topics (e.g., from climate information to vulnerability to response) (Bales and Morehouse, 2001). CLIMAS involved, from its initiation, researchers from physical and social science disciplines who were committed to interacting frequently and working jointly on some activities. Input from stakeholders, to be solicited in varied ways, was intended to shape the project's research agendas, activities, and resultant products. Relationships with stakeholders were to be maintained so that the impacts of research results and products could be assessed. As an integrated assessment effort, CLIMAS differs from other national and regional assessments (e.g., National Assessment Synthesis Team, 2000; Southwest Assessment Team, 2000) in that it was intended to be a continuing, evolving process rather than a series of studies culminating in end products (Bales and Morehouse, 2001).

1.3 RESEARCH OBJECTIVES

The primary objective of this work was to identify, design, and implement a coordinated stakeholder driven research agenda concerning hydroclimatic forecasts, in the context of the CLIMAS project. The objective was broadly defined to maintain flexibility to respond to input from stakeholders. Specific objectives were as follows:

i. Through direct interaction, establish an understanding of selected groups with interests related to hydroclimatic variability in the U.S. Southwest, in terms of their use of hydroclimatic information and forecasts.

ii. Review weather, climate, and hydrologic forecasts available to stakeholders in the U.S. Southwest.

iii. Develop a coordinated research agenda related to hydroclimatic forecasts that reflects opportunities for scientific advancement, expressed stakeholder needs, and an understanding of the context within which hydroclimatic forecasts exist relative to other decision making considerations.

iv. Develop a framework for evaluating hydroclimatic forecasts in ways that have meaning for diverse stakeholders.

v. Apply the forecast evaluation framework to the seasonal climate outlooks issued by the National Weather Service (NWS) Climate Prediction Center (CPC).

1.4 ORGANIZATION

The methods for achieving each of these objectives are quite different, as is the relevant literature. Thus, methodological descriptions and literature reviews are integrated into each chapter rather than presented in Chapter 1.

Chapter 2 describes the organization and conduct of interactions with three groups of stakeholders: water resources managers, cattle ranchers, and wildland fire managers. Different forums and methods were used for the interactions, depending on the stakeholder group, available opportunities, and participation of other researchers. The interactions provided the basis for developing insights about (1) stakeholder use of hydroclimatic information and forecasts, (2) the organization of stakeholder interactions, and (3) the conduct of stakeholder interactions. These insights provide the basis for recommending several priorities for stakeholder driven hydroclimatic research.

Chapter 3 describes a survey made from April 1998 - March 2000 of weather, climate, and hydrologic forecasts with coverage of the U.S. Southwest, with an emphasis on the Colorado River Basin. The survey examines the types of forecasts that were issued, the organizations that provided them, and techniques used in their generation. The survey also reflects discussions with key personnel from organizations involved in producing or issuing forecasts, providing data for making forecasts, or serving as a link for communicating forecasts. Issues addressed include the complex and constantly evolving forecast milieu, designation of forecasts as official or experimental products, general lack of documentation, difficulties in forecast interpretation, flexibility of forecasting operations, current status of monitoring of forecast performance, and prospective future issues related to forecasting. Recommendations are directed toward improved product content and communication, modeling capabilities, and forecast evaluation.

Chapter 4 presents a coordinated research agenda focused on hydroclimatic forecasts. The agenda reflects opportunities for scientific advancement, expressed stakeholder needs, and an understanding of the context within which hydroclimatic forecasts exist relative to other decision making considerations. The chapter relates the agenda to other CLIMAS research activities, and shows how the agenda provides avenues for making research in other programs more usable to stakeholders as well.

Chapter 5 describes the development and application of a framework for evaluating forecasts from the perspectives of diverse stakeholders, including the lead times, seasons, and criteria relevant to their specific situations. The forecasts evaluated are the official seasonal temperature and precipitation outlooks issued by the National Weather Service Climate Prediction Center. Consideration is given to how forecast formats can affect the ease, accuracy, and reliability of interpretation, and leads to the suggestion that the "climatology" designation be modified to better reflect complete forecast uncertainty. A graphical product is presented that tracks time evolution of the forecasts and subsequent observations. This work provides a framework for evaluation, consisting of multiple quantitative forecast performance criteria that allow individuals to access results at the level they are capable of understanding, while offering opportunity for shifting to more sophisticated products. Examples show how results targeted for specific user perspectives can provide different assessments of forecast performance.

Finally, Chapter 6 summarizes the essential conclusions and provides recommendations for future stakeholder interactions and more effective use of hydroclimatic forecasts. The chapter also recommends several priorities for hydroclimatic research and interdisciplinary efforts that will require collaboration with social scientists as well as stakeholders.

1.5 PUBLICATION OF RESEARCH

The work presented in Chapter 3 has resulted in a publication for the journal *Climate Research* that is in final review (Hartmann et al., 2002a). The work presented in Chapter 5 has resulted in a publication for the *Bulletin of the American Meteorological Society* that is also in final review (Hartmann et al., 2002b). In addition, other publications are in preparation:

- An article for *EOS, Transactions of the American Geophysical Union* (AGU), on lessons for physical scientists about interacting with stakeholders that may be skeptical about scientists and their research.
- Two publications on the role of climate variability, forecasts, and forecast skill for the ranching sector. One is for the *Journal of Range Management*, targeted at range and watershed management professionals, while the other is for *Range*, a broadly distributed publication for ranchers. Both will be co-authored with other CLIMAS team members involved in interactions with the ranching sector.
- A publication on the role of climate variability, forecasts, and forecast skill for the wildland fire management sector, in a journal to be determined. The article will be co-authored with other CLIMAS team members involved with the wildland fire management sector.
- Additional publications on the CLIMAS experience with stakeholder driven research and stakeholder interactions, to be co-authored with other CLIMAS researchers in journals to be determined.

CHAPTER TWO

INTERACTIONS WITH STAKEHOLDERS

2.1 INTRODUCTION

Stakeholder driven research requires interaction with stakeholders. While the preceding statement is simplistic, its implementation is not. Stakeholders must be identified and specific types of interactions must be designed and implemented. Insights relevant to scientific research must be extracted from the interactions, and finally, used to adapt the agenda and activities within a research program.

Stakeholders are individuals or groups that have interests affected by conditions and activities within a region, or that have the ability to affect regional conditions and activities (Phillips, 1997; Mitchell, 1997). Thus, scientific researchers can be stakeholders to the extent that their activities (1) are affected by the interests of other stakeholders, availability of research funds, and implementation of their findings or use of their products, or (2) affect the decisions or conditions facing other stakeholders. Agencies and other organizations can be considered stakeholders, although they may have interests and pressures different from their personnel, who then may be considered separate stakeholders.

This chapter describes interactions with stakeholders in which the author participated during 1998 - 2001, related to use of hydroclimatic information and forecasts in the Southwest. The stakeholders included individuals involved in water management, ranching, and wildland fire management. Different forums and methods were used for the interactions, depending on the stakeholder group, available opportunities, and participation of other researchers. The primary objectives of the interactions were to develop an understanding of (1) stakeholder use of hydroclimatic information and forecasts, and (2) priorities for stakeholder driven hydroclimatic research. However, the experience and comments from the stakeholders provided the basis for developing insights along other lines as well, concerning (3) the organization of stakeholder interactions, and (4) the conduct of stakeholder interactions.

2.2 BACKGROUND

Effective stakeholder driven research requires more than acknowledging that traditional approaches for conducting and presenting research results may limit usability by a broad range of decision makers. Rather, stakeholder driven research requires a commitment to iterative bidirectional interaction between research scientists and stakeholders (Changnon, 1983, 1987). Many social science methods exist to facilitate individual stakeholder interactions (Whyte, 1977; Schoenberger, 1991; Bernard, 1994; Rubin and Rubin, 1995; Mohr, 1999). However, in a broader context, the framework for stakeholder interaction can take several forms. A formal organizational analysis of scientist-stakeholder interactions is best left to social scientists. However, the following types of scientist-stakeholder relationships are presented to illustrate that the structure of the interactions described in this chapter were not predetermined. Other options were available, offering a different balance between effort and effectiveness, but they were not selected.

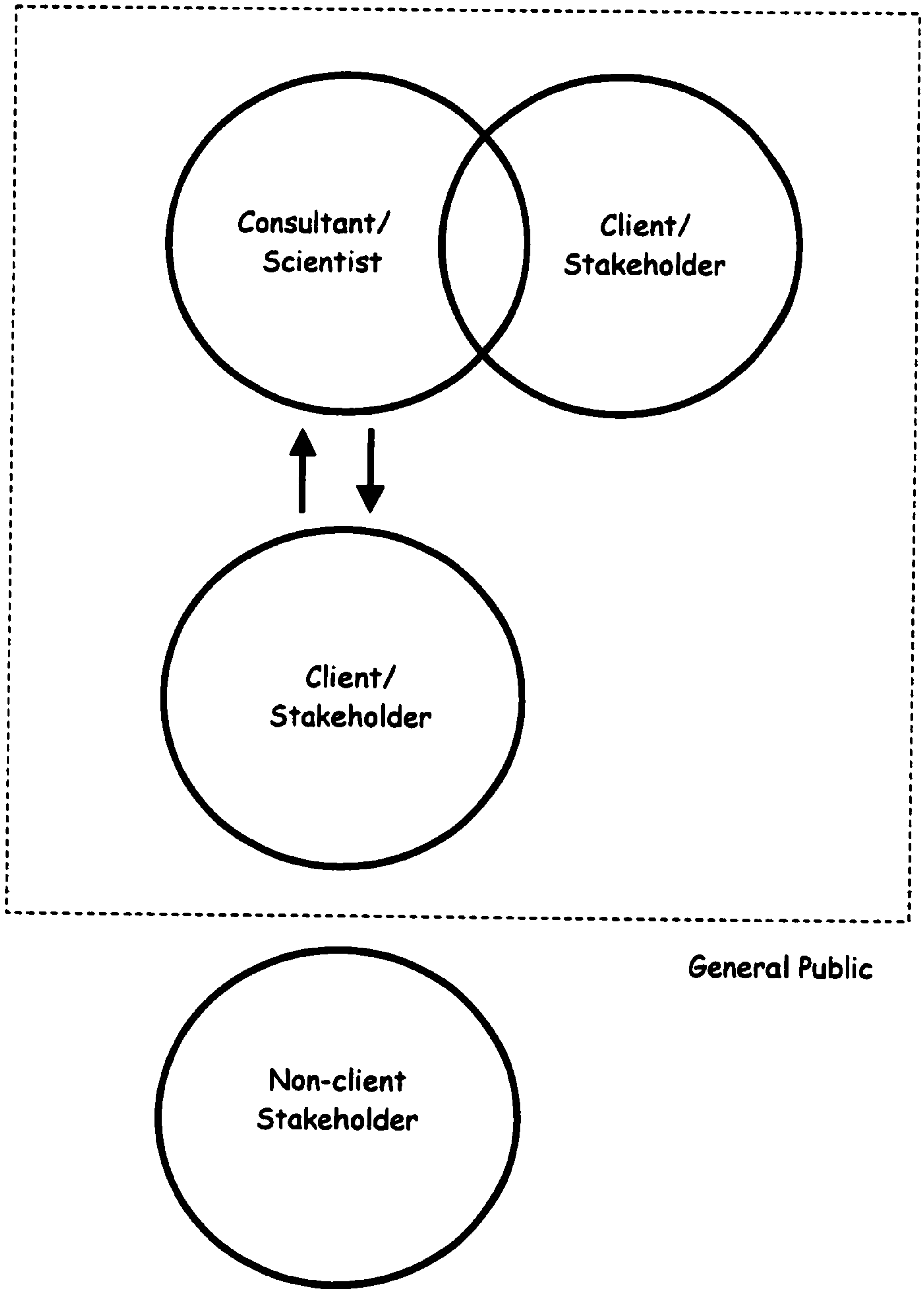
2.2.1 Client-Consultant Relationship

Figure 2.1 schematically illustrates the relationship between scientists and stakeholders using a model typical of engineering and applied research. In this model, the stakeholders become, in essence, clients of the researchers who, in turn, act as consultants.

The Pacific Northwest and California RISA Projects, funded by NOAA's Office of Global Programs (OGP), appear to use this approach. Researchers in those projects have worked closely with a limited number of stakeholders (e.g., the California Department of Water Resources) to develop customized analyses, products and tools for use by the "client" agencies (Pulwarty, 2001a).

The client-consultant relationship offers several advantages for stakeholder driven research. The approach allows researchers to develop close relationships with the stakeholders and understand even intricate details about their operations, information requirements, and decision making processes. Close relationships may be particularly attractive for research programs targeted at "end-to-end" modeling or forecasting, whereby basic models or applications (e.g., global climate models) are connected to decision support tools designed for specific users (e.g., reservoir operation optimization procedures). When implemented in the private sector, the client's willingness to pay reflects the worth of the consultant's efforts and products. When implemented in the public sector, the client becomes an advocate for continued project funding because the project directly serves the client's interests.

Figure 2.1 Client-consultant relationship between research scientists and stakeholders. Client stakeholder relationships with scientific researchers vary in their closeness, but non-client stakeholders are excluded unless they become clients, as is the general public.



However, the client-consultant relationship also presents challenges for stakeholder driven research. Client-consultant relationships do not favor an equitable distribution of the impacts of research funding. The selection of stakeholders is likely to favor arrangements offering high probabilities of rapid success and operations with high economic value, as a way to assure research funding. Such stakeholders typically consist of organizations having staff with technical training, which facilitates communication between consultant and client because both share common educational backgrounds. Further, these stakeholders typically have the resources (e.g., computers, staff) to make use of the research products, as well as flexibility in management options (e.g., substituting surface water for groundwater). Many water management agencies, hydropower providers, and high value agricultural operations fit this profile. Relationships with stakeholders that have difficulty attending meetings (e.g, rural ranchers), lack resources or easy options for adjusting their operations, or require training about basic concepts are not attractive prospects for developing client-consultant relationships.

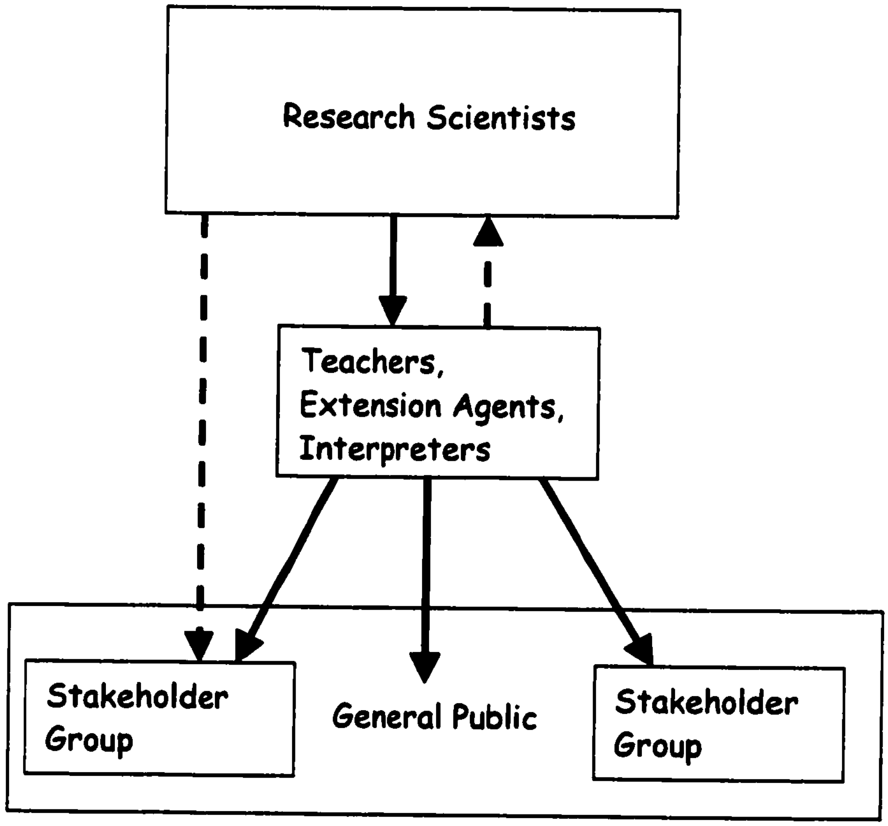
Further, client-consultant relationships are not easily scalable to larger numbers of clients. Scientists involved in client-consultant relationships can serve only a limited number of stakeholders because of the need to develop close relationships. Once research or products have been developed for one client, expanding service to a new client requires developing a new close relationship and adjusting prior work to the specific needs of the new client. In addition, the client-consultant relationship provides disincentives for broad dissemination of research and products. In situations where a private sector client provides funding, there is pressure for the research and products to have limited availability. The client desires competitive advantages in their exclusive use of the research products. The consultant desires competitive advantages in seeking out new clients (even in the pursuit of public funding), and so is likely to be less motivated to publish their methodologies or broadly distribute their products (e.g., models, data sets).

2.2.2 Technology Transfer and Outreach

Figure 2.2 schematically illustrates the relationship between scientists and stakeholders using a model typical of many scientific research programs. In this model, research is driven by gaps in scientific understanding, availability of observations, and technological capabilities. Through technology transfer, products are delivered to users after the research is completed, often with additional effort to create general application-related material (e.g., fact sheets). Outreach typically consists of presentations to various groups, focusing on education (e.g., materials for primary and secondary schools) or materials for the general public (e.g., brochures). Often, researchers themselves do not interact with the stakeholders. Rather, the technology transfer and outreach activities are often handled by individuals who are not directly involved in the research. There are exceptions whereby the scientists interact directly with some stakeholders (e.g., engineering continuing education or short courses).

The Science and Technology Center for the Sustainability of Semi-Arid Hydrology and Riparian Areas (SAHRA), funded by the National Science Foundation, makes extensive use of this approach (SAHRA, 2001a). Between 10-15% of the Center's

Figure 2.2 Technology transfer and outreach relationship between research scientists and stakeholders. Dashed arrows indicate possible interactions.



$16 million budget is dedicated to education and outreach over a five-year period (SAHRA, 2001b). Researchers and education specialists are used to develop products and conduct events involving a broad array of stakeholders. While researchers sometimes take part in the technology transfer and outreach activities, the interactions are not specifically designed to elicit stakeholder input for the purposes of affecting research directions.

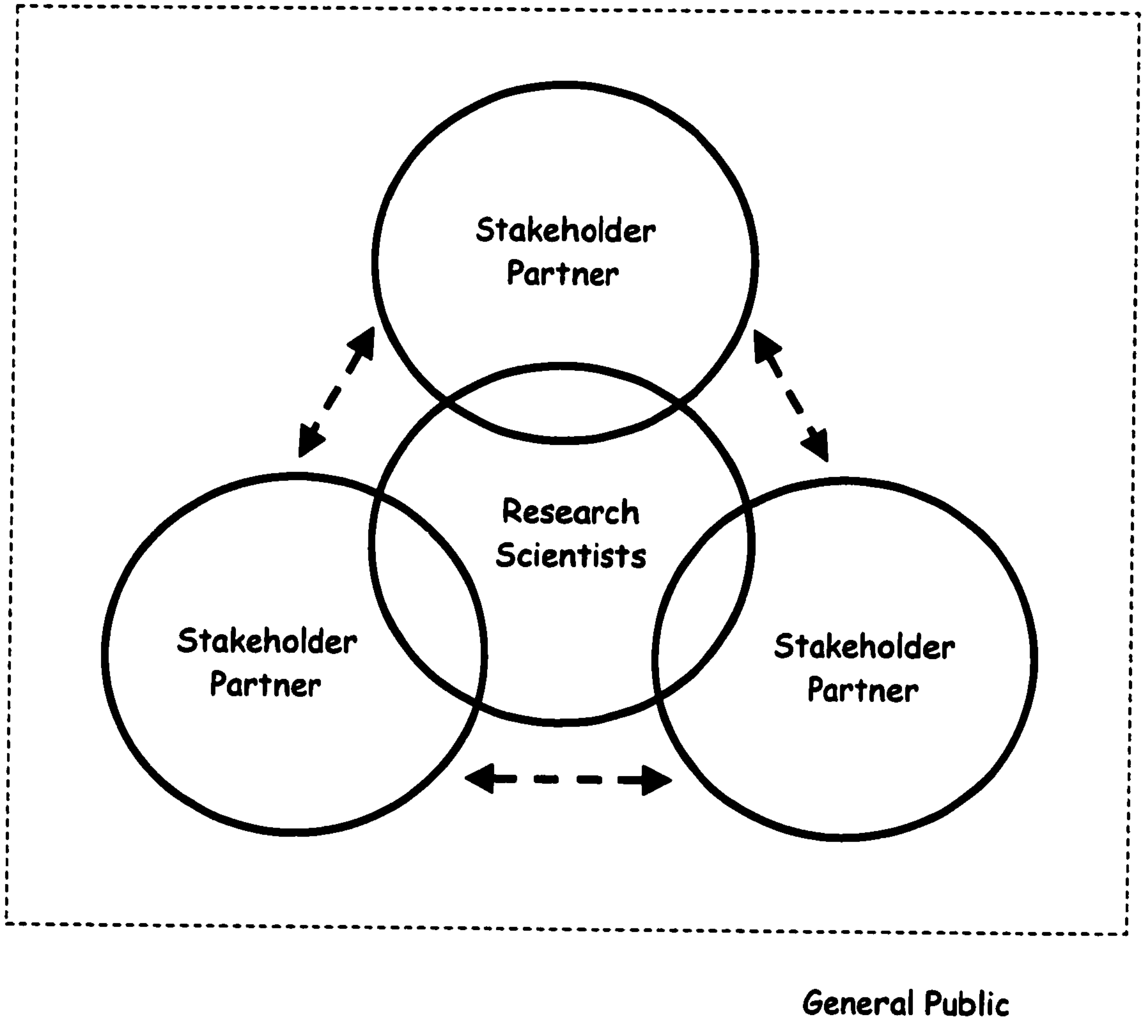
The technology transfer and outreach model offers several advantages for communication and dissemination of research. The most notable is that activities are typically aimed at broad and diverse audiences. For researchers, additional advantages relate to efficiency. Researchers can maintain control of their research efforts, without having to respond to external requests, and can focus on their research without taking time away from their research activities to participate in stakeholder interactions.

However, the technology transfer and outreach model has serious limitations for stakeholder driven research. Most importantly, while technology transfer and outreach provides some level of interaction with stakeholders, the research itself is not stakeholder driven. The approach allows the research to proceed and scientists interact with stakeholders only after reaching milestones in their work, if at all.

2.2.3 Research Partnership

Figure 2.3 schematically illustrates the research partnership relationship between scientists and stakeholders using a model not often seen in scientific research programs. In this model, the scientists and stakeholders develop close relationships characterized by

Figure 2.3 Research partnership relationship between research scientists and stakeholders. Dashed arrows indicate possible interactions. The general public is generally excluded, although some products may be accessible to them.



high levels of trust. The stakeholders are seen as integral partners in the prioritization, design, or conduct of the research.

The Semi-Arid Land Surface-Atmosphere (SALSA) program exemplifies an attempt to implement the research partnership approach (SALSA, 2000) in its long-term monitoring and modeling efforts. SALSA was funded through a diverse array of federal programs and was designed to foster participation, exchange, and cooperation among scientists, resource management agencies and organizations, and residents of the upper San Pedro watershed in southern Arizona and adjacent areas in Mexico. Scientific questions were focused on those requiring interdisciplinary collaboration. SALSA made extensive use of volunteers, including non-scientists, in the planning and conduct of field measurement campaigns.

Research partnerships offer several advantages for stakeholder driven research. The high level of involvement of stakeholders, if the partnership is successful, helps develop a strong cadre of advocates for the research program. Where resource management issues are contentious and disputes often arise over "facts", stakeholder participation in the research can help develop ownership and confidence in the information ultimately used in the decision making.

However, partnerships also present challenges for stakeholder driven research. Most notably, research partnerships require tremendous effort and commitment on the part of both researchers and stakeholders. Projects require long lead times for development, including seemingly endless meetings, and cultivation and coordination of many participants with different backgrounds and capabilities. Additionally, the partnership approach may require efforts to maintain equitable involvement of stakeholders with competing interests.

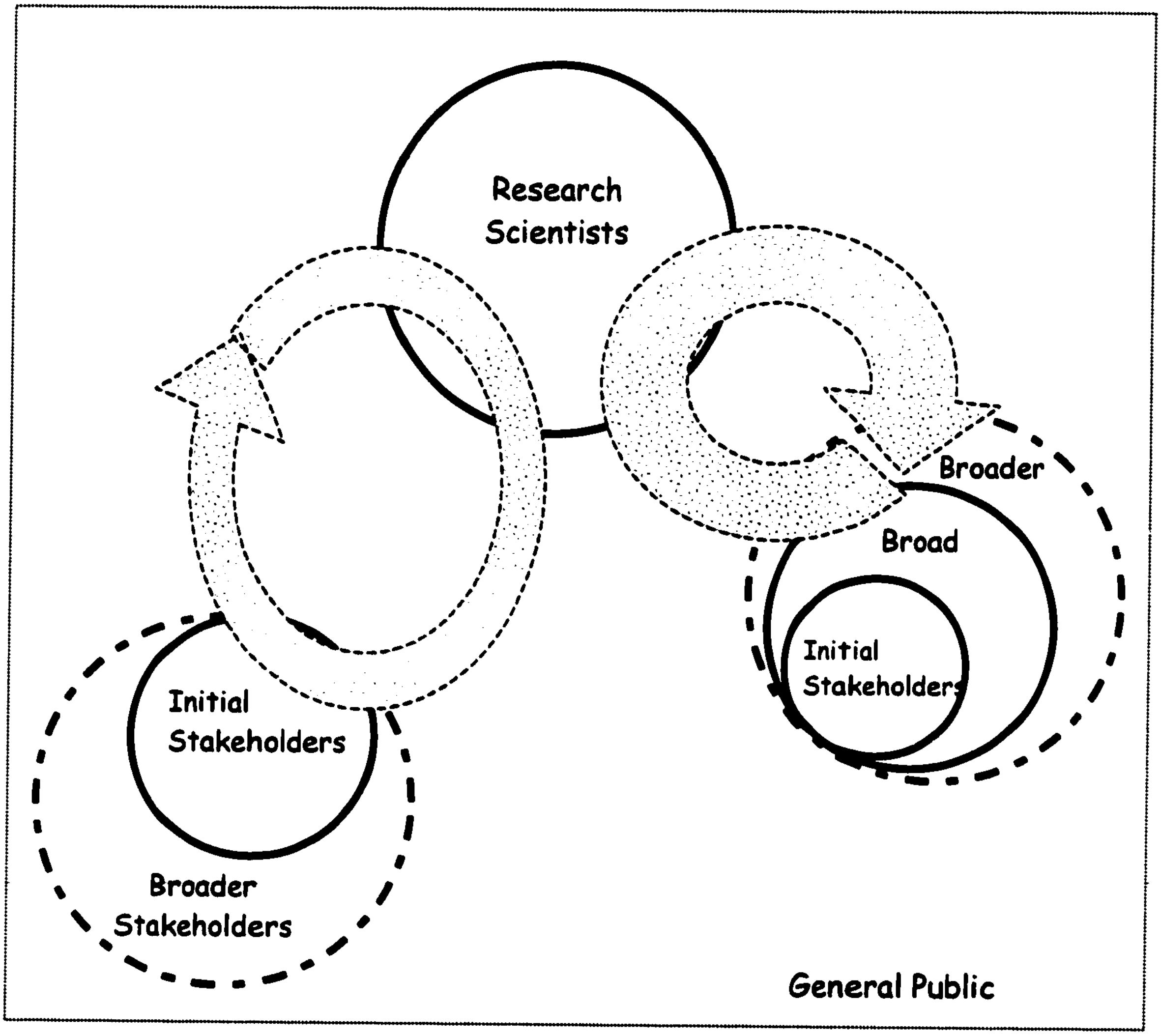
2.2.4 Public Participation

Figure 2.4 schematically illustrates a public participation relationship between scientists and stakeholders using a model not often seen in scientific research programs. This model is based on the public participation process often used in public resource management programs. In this model, the research organizations develop opportunities for interaction with stakeholders, actively solicit stakeholder comments, and have a commitment to responding to stakeholder input. However, stakeholder expectations are not raised to the level of a partnership with scientists.

Interactions with stakeholders occurring as part of the CLIMAS project generally fit the public participation model. Stakeholders from selected socioeconomic sectors (e.g., water management) or communities (e.g., Benson, Arizona) have been engaged using a variety of social science techniques and settings. The goal of the interactions has been to determine research directions and the types of products that would be relevant across a broad range of potential users. However, the project has not attempted to incorporate all stakeholders equally or in ways designed to balance or resolve fact-based conflicts over resource management issues.

The public participation model offers several advantages for stakeholder driven research. The primary advantage is flexibility; the issues involved are not so contentious as the issues addressed in the research partnership model and stakeholder involvement is

Figure 2.4 Public participation relationship between research scientists and stakeholders. Relationships between scientists and stakeholders vary in closeness. Relationships begin with small groups of stakeholders that can expand in number and diversity. The general public is generally excluded, although some products may be accessible to them. Dashed lines indicate potential routes for diffusion.



not critical for the acceptability of eventual resource management decisions. Thus, scientists can target opportunities without fear of disrupting the balance of their relationships with different groups. In addition, these differences allow scientists the flexibility to clearly communicate that their only agenda is improving the stakeholder orientation of their research, not promoting agreement about resource management decisions.

However, the public participation model also presents challenges for stakeholder driven research. Like the partnership model, the public participation model requires effort to engage many diverse stakeholders, although to a lesser extent. Once stakeholders have been engaged, however, the public participation model requires a commitment for the engagement to be continued until there is formal closure of the relationship. Otherwise, if stakeholders perceive the scientists to be nonresponsive to their input or the time between interactions to be excessive, potential exists for the stakeholders to be disappointed and skeptical of subsequent research efforts.

2.3 INTERACTIONS WITH STAKEHOLDER GROUPS

The interactions with stakeholders described herein occurred during 1998 - 2001. Different forums and methods were used for the interactions, depending on the stakeholder group, available opportunities, and participation of other researchers. All stakeholder interactions were designed to enable qualitative, rather than quantitative, analysis. Not all interactions led to hydrologic research activities, but they did provide insight about the priorities and expectations of stakeholders.

2.3.1 Water Resources Management

Stakeholders with interests in water resources management encompass a broad variety of individuals and organizations representing local, regional, and national jurisdictions. Interactions with water resources management stakeholders largely developed on an ad hoc basis as the CLIMAS project and hydroclimatic research activities evolved and as opportunities for interaction arose in external forums. Early interactions were geared toward finding out how stakeholders perceived information and conditions, while later interactions were focused on how stakeholders perceived material developed in response to earlier input.

Semi-structured Interviews

Interactions with water management stakeholders began as a consequence of the 1997 workshop on climate variability and change in the Southwest (Merideth et al., 1998). Workshop organizers brought together representatives from the private sector, governmental agencies, academia, and the general public to focus on the current knowledge, information needs, and potential responses to climate variability in the region. Several presentations and lively discussion in breakout groups focused on the strong and rapidly intensifying El Niño event and potential implications for southwestern climate and stakeholders. However, discussions revealed that no researchers were monitoring, or had plans to monitor, how stakeholders were accessing, interpreting, and using hydroclimatic information and forecasts in their water management decisions.

As a result, a project was developed for implementation by a Masters student. Briefly, the purpose of the project was to investigate agency actions during the 1997-98 El Niño event. The project addressed six main topics: (1) regional impacts of the El Niño event, (2) sources of information about El Niño and hydroclimatic variability, (3) institutional responses to the 1997-98 El Niño event, (4) perceptions of the utility of the hydroclimatic forecasts and informational products, (5) user satisfaction with the products and their decisions, and (6) potential improvements in the utility of products. The project and research results are described in detail in Pagano et al. (1999, 2001, 2002).

For this effort, stakeholder interactions were designed as extended semi-structured interviews and conducted by a colleague (T. Pagano, Department of Hydrology and Water Resources, University of Arizona [UA]). Between May 1998 and January 1999 (mostly during summer 1998), each participant was engaged in a series of interviews, consisting of up to three sessions lasting one to five hours each, followed by opportunity to review statements and provide corrections, clarification, and elaboration. Prior to the first interview, participants received an 11-page interview guide consisting of information about the study, discussion questions, and several relevant climate products. The guide was developed with the assistance of the UA Bureau of Applied Research in Anthropology (BARA) following standard practices (Bernard, 1994; Rubin and Rubin, 1995). Additional details are provided by Pagano et al. (1999, 2002).

Stakeholders were selected for participation by virtue of being key personnel from agencies that had responsibility for managing water supplies or flood hazards for local, state, or federal jurisdictions within Arizona. Participating stakeholders are listed in Table 2.1. Agencies and individuals were identified based on an understanding of Arizona's water management milieu and recommendations by others, including the solicited agencies. Not all contacted agencies chose to participate; 14 of 30 declined, although four of the 14 did consent to single 5- to 10-minute interviews. Reasons for non-cooperation included lack of perceived relevance, disinterest in the effort required, and suspicion of non-confidentiality or motives.

Forecast Assessment Workshop

Early in the CLIMAS project, hydroclimatic predictability was identified as a potential area of research and was the central topic of one of the first CLIMAS interactions with a group of stakeholders. The setting was a two-day workshop held at the University of Arizona (Forecast Assessment Workshop, Institute for the Study of [ISPE] Earth, UA, Tucson, Arizona, 8-9 July 1998).

Stakeholder interactions at the workshop were organized around focused discussions that were designed to address predetermined topics (Whyte, 1977; Rubin and Rubin, 1995). Five areas were addressed: (1) forecast products that were currently available for the Southwest, (2) perceptions about the use of forecasts in decision making, (3) extant assessments of the strengths and limitations of available forecasts, (4) requirements and approaches for evaluating forecast performance, and (5) requirements and approaches for improving hydroclimatic predictability. Table 2.2 lists questions posed for each topic. Participants were provided with a list of questions prior to the

Table 2.1. Affiliations of water resource management stakeholders participating in interaction events.[1]

Semi-structured Interviews	Forecast Assessment Workshop
Bureau of Reclamation Districts (Upper and Lower Colorado River)	NWS[2] Weather Forecast Offices (Phoenix and Tucson, Arizona)
Arizona Department of Water Resources	NWS[2] Colorado Basin River Forecast Center
Arizona Division of Emergency Management	NWS[2] Office of Hydrology
Office of the Governor	Natural Resources Conservation Service
Salt River Project	Bureau of Reclamation
Gila River Water Commission	United States Geological Survey
Santa Cruz Active Management Area	Salt River Project
County Flood Control Districts: Pima and Maricopa	Western Regional Climate Center
County Emergency Management Agencies (five different counties)[2]	NOAA[2] Office of Global Programs
Tucson Water	CESBIO, France
	Portland State University Department of Civil Engineering and Environmental Sciences
	UA[2] Institute for the Study of Planet Earth
	UA[2] Department of Hydrology
	UA[2] Department of Civil Engineering
	UA[2] Department of Management and Policy

[1]Detailed list of names and some affiliations omitted to avoid violating confidentiality (Dunn and Chadwick, 1999).
[2]NWS: National Weather Service, NOAA: National Oceanic and Atmospheric Administration, UA: University of Arizona.
[3]Counties not named to preserve participant confidentiality.

Table 2.1, continued. Affiliations of water resource management stakeholders participating in interaction events.[1]

Forecast Evaluation Workshop	**ASCE Conference Workshop**
NWS[2] Weather Forecast Office (Tucson, Arizona) NWS[2] Colorado Basin River Forecast Center Arizona Department of Water Resources Salt River Project Pima County/Tucson Department of Emergency Management UA[2] Institute for the Study of Planet Earth UA[2] Department of Hydrology and Water Resources	Salt River Project City of Tempe, Arizona Maricopa County Flood Control District Private sector engineering firms (two) Arizona State University University of California-Los Angeles

[1]Detailed list of names and some affiliations omitted to avoid violating confidentiality (Dunn and Chadwick, 1999).
[2]NWS: National Weather Service, UA: University of Arizona.

Table 2.2. Focused discussion topics addressed at the Forecast Assessment Workshop, 8-9 July 1998, University of Arizona, Tucson, Arizona.

Topic and Related Questions
Current Products
What are your current forecasts for the Southwest?
How do you decide what products to generate?
How are the forecasts currently made?
What has been the evolution of your forecasts?
What other southwestern forecasts are you aware of?
What forecasts are anticipated in the near-term future?
What do private services offer?
Forecast Use
Who are your intended "customers"?
What are the intended uses of your forecasts?
How are your "customers" using your forecasts?
How could they use your forecasts?
Do they understand your forecasts?
What accuracy do your "customers" require?
What is the value to your "customers"?
Is there a formal mechanism for user interaction?
Forecast Assessments
What assessments exist for your products?
What were the methodologies and results?
If assessments are lacking, what is your impression of the quality of the forecasts?
What are the limitations inherent in your products (assumptions, data, methodology)?
What errors result from each limitation?
Forecast Evaluations
What forecasts have the highest priority for evaluation?
What data is available for evaluating forecasts?
How should changes in forecast methods be handled?
What evaluation approaches should be used?
Improved Forecasting
What new forecasts could or should your agency produce?
How would the forecasts be better than those currently available?
What research activities are needed to make them?
How can the Climate Assessment for the Southwest (CLIMAS) project help?

workshop, to ensure they could gather the appropriate information from other staff members, if necessary. The workshop was facilitated by the author.

Stakeholders involved in the workshop are listed in Table 2.1. Almost all participants were invited, although a broad group of CLIMAS contacts was notified about the workshop and led to participation by a few university personnel. Invited participants consisted of key personnel from agencies involved in producing or issuing forecasts, providing data for making forecasts, or serving as a link for communicating forecasts. Individuals were selected based on an understanding of the forecasting milieu and recommendations by others, including the solicited personnel.

Workshop at American Society of Civil Engineers Conference

Another stakeholder interaction attempted to involve more water resource management practitioners, especially civil engineers. A special session and workshop was organized as part of an annual meeting of the Water Resources Planning and Management Division of the American Society of Civil Engineers. The workshop was held 8 June 1999 in Tempe, Arizona. Participants (Table 2.1) were self-selected on the day of the workshop based on their examination of the conference schedule and session description, which was erroneously listed as a panel discussion rather than an interactive workshop.

The special session included presentations by several CLIMAS researchers and addressed goals of the CLIMAS project, use of hydroclimatic information during the 1997-98 El Niño event, availability of hydroclimatic forecasts for the Southwest, paleoclimatologic data for the Southwest, assessments of the sensitivity of the urban water sector to climate variability in the Southwest. The workshop component was organized around focused discussions designed to address predetermined topics (Whyte, 1977; Rubin and Rubin, 1995). Discussions were facilitated by a CLIMAS social scientist (B. Morehouse, ISPE, UA). The three topics included: (1) whether participants used any of several example hydroclimatic information and forecast products, (2) identification of climate information needed for the activities and decisions of civil engineering, and (3) how further stakeholder interactions with civil engineers might best be organized and implemented. A 300-year (1700-1999) paleoclimatologic reconstruction of the Palmer drought severity index was used to explore how concepts of climate non-stationarity were incorporated into civil engineering design. Seasonal climate and water supply forecasts were used to prompt discussion on how climate variability has been managed in civil engineering operations.

Forecast Evaluation Workshop

Based on earlier interactions across a range of stakeholders, it became clear that the lack of any quantitative basis for establishing forecast credibility was limiting the use of hydroclimatic forecasts. Iterative stakeholder interaction was sought after development of a framework for evaluating forecasts and application to seasonal climate outlooks (see Chapter 5). The interaction was organized as a one-day workshop held at the UA (Forecast Evaluation Workshop, ISPE, UA, Tucson, Arizona, 20 November 2000).

The goal of the workshop was to obtain feedback about the process of, and tools for, evaluating climate forecasts. Participants were provided with an agenda prior to the workshop, but not evaluation products. Table 2.3 lists details about the workshop topics, which included: (1) interpretation of climate forecasts, (2) performance attributes of climate forecasts, (3) issues in forecast evaluation, (4) identifying decision cycles, (5) graphical comparisons of forecasts and observations, (6) quantitative evaluation criteria, and (7) implications of forecast quality. The workshop elicited comments from stakeholders using focused discussion (Whyte, 1977; Rubin and Rubin, 1995) and made extensive use of worksheet exercises, all developed prior to the workshop. Appendix A contains the detailed agenda used for the workshop, which was facilitated by the author. Training materials, including worksheet exercises, are available from the author.

Attendance was limited to only a few participants, to allow for extended in-depth discussion of technical details. Participants were invited based on their understanding of and professional involvement with water resources issues (e.g., water supply, emergency management) and climate variability, as well as prior interaction with CLIMAS researchers. Several hydrologic researchers also attended. Participant affiliations are listed in Table 2.1.

2.3.2 Ranching

Cattle ranching has important cultural, historical, ecological, and political significance in the Southwest and was an early focus of CLIMAS interaction with stakeholders, incorporating survey questionnaires and structured discussions with

Table 2.3. Topics and objectives of Forecast Evaluation Workshop, 20 November 2000, University of Arizona, Tucson, Arizona.

Topic and Related Objectives
Climate Forecasts: Availability and Interpretation Assess the ease, accuracy, and reliability of interpretation of seasonal climate forecast through examination of (1) several different forecasts that have, generally, the same type of content, but in different formats; (2) probability of exceedance forecasts issued by the National Weather Service Climate Prediction Center (CPC); and (3) the role of ancillary information.
What Makes a Forecast "Good" or "Bad"? Develop concepts, prior to seeing results, about important performance attributes of probabilistic forecasts.
Issues in "Valid" Forecast Evaluation Address problems related to evaluation of seasonal probabilistic forecasts.
Decision Calendars Determine an effective format for users to communicate which forecasts they use in making decisions (i.e., the months forecasts must be issued, the seasons forecasts must cover).
Graphical Comparison of Forecasts and Observations Obtain feedback about recently developed graphical products that show the historic record of a series of temporally evolving probabilistic forecasts (i.e., CPC climate forecasts) and observations.
Quantitative Forecast Evaluation: Appropriate Criteria, with Applications Assess different forecast evaluation criteria for CPC seasonal climate forecasts (i.e., probabilities for tercile categories).
Revisitation of Earlier Issues Determine if participants have changed perceptions of issues brought up earlier in the workshop, after having completed worksheet exercises on graphical and quantitative evaluations.
Implications of Present Forecast Quality Explore how "good" climate forecasts must be before they are useful for water management.

ranchers (Conley et al., 1999). Those interactions showed that the vulnerability of ranching operations stems, in part, from their dependence on rainfed rangelands, although specific vulnerabilities depend on the location and type of operations. For example, cow-calf operations consist primarily of breeding females used to produce calves for the feedlot market; they have long-term sensitivity to climate through impacts of range condition on calf health for six months after birth and heifer health prior to calving and even a year later. In contrast, steer operations purchase calves each year to graze for several months, after which they are sold; consequently, steer operations are not as sensitive to climate variability.

An expanded survey of a broader group of ranching stakeholders was developed by CLIMAS social scientists (D. Hadley, Arizona State Museum, UA), with the focus remaining on the vulnerability of the ranching sector to climate variability. Subsequent stakeholder interactions were designed to motivate members of the ranching sector to complete a survey questionnaire about their ranching operations and how they had been affected by drought. The goals of each interaction were to (1) explain the CLIMAS project, (2) give a presentation on climate variability in the Southwest, (3) foster open-ended discussion, and (4) request that each rancher complete the questionnaire and return it in the mail. The discussions attempted to solicit details about their ranching operations, perceptions about climate changes that they might have observed over the past decades, how climate conditions affect their operations, and how they perceive or use climate information and forecasts.

Interactions with the ranchers used a team approach, with the team consisting of at least one social scientist and one physical scientist. Meeting arrangements were made by one of the social scientists. Typically, a conservation district meeting began with an introduction of the researchers, followed by standard agenda items; more formal interactions usually began late in the meeting. A physical scientist (T. Pagano or the author, Department of Hydrology and Water Resources, UA) gave a 20-minute presentation on climate variability and research. With the presentation, participants were given a copy of an informal information packet, "Southwest Climate in a Nutshell" (Pagano, 1999). The packet was designed to help build relationships by providing material (with contact information) to take home and share with others. It used informal language and different versions included material customized to show data for locations near the meeting. Discussion followed the presentation and typically lasted 30 minutes to more than an hour. The CLIMAS scientists took notes and debriefed after each meeting to share notes and perceptions about stakeholder comments.

The social scientists organized meetings with Natural Resources Conservation Districts (NRCDs) throughout Arizona. Conservation districts are subdivisions of state or tribal governments, but are also legislated partnerships between the state and the federal Natural Resources Conservation Service (NRCS) (Arizona State Land Department, 1999). The districts were selected in an attempt to ensure representation of ranchers with operations in several ecological regions (D. Hadley, Arizona State Museum, personal communication, 1999). Table 2.4 lists the districts and the meeting locations and dates. The meetings varied in size from four or five individuals to nearly 40, with the Annual

Table 2.4 Meeting information for interactions with ranching stakeholders.

Conservation District	Meeting Location (Arizona)	Meeting Date
Malapai Borderlands Group	Douglas	22 May 1999
Southern Arizona Cattleman's Protective Assoc.	Marana	9 October 1999
Yavapai Cattlegrower's Association	Skull Valley	20 November 1999
Winkelman NRCD[1]	Mammoth	9 July 2000
Hereford NRCD[1]	Sierra Vista	19 July 2000
State Association of Conservation Districts	Pinetop	4 August 2000
Whitewater Draw NRCD[1]	Douglas	8 August 2000
Verde NRCD[1]	Camp Verde	9 August 2000
Moenkopi NRCD[1]	Moenkopi	9 August 2000
Navajo Mountain NRCD[1]	Shonto	10 August 2000
Coconino NRCD[1]	Flagstaff	10 August 2000
Gila River NRCD[1]	Sacaton	19 August 2000
East Maricopa NRCD[1]	Higley	20 September 2000
Willcox-San Simon NRCD[1]	Willcox	25 October 2000
Redington-San Pedro NRCD[1]	Benson	5 December 2000

[1]NRCD = Natural Resources Conservation District.

Meeting of State Conservation Districts even larger. Most participants were ranchers or conservation district staff engaged with the ranching community, although some farmers came to the meetings as well. As a rough measure of total attendance, over 450 information packets were distributed at the meetings.

2.3.3 Wildland Fire Management

Wildland fires have historically been an important natural process throughout the Southwest, resulting from a reliably arid spring and summer, followed by lightning storms that occur prior to the summer monsoon (Swetnam and Betancourt, 1990). In contrast to water management and ranching stakeholders, wildland fire management stakeholders included individuals with responsibilities in regions outside the Southwest, as well as those with southwestern jurisdictions.

National Workshop 2000

Prompted by seasonal climate forecasts for a second dry winter, due to a long-lasting La Niña event, the CLIMAS core office (B. Morehouse, ISPE, UA) initiated interactions with stakeholders concerned with wildland fire management. The earliest formal interaction occurred through a two-day workshop (The Implications of La Niña and El Niño for Fire Management: A CLIMAS Workshop, ISPE, UA, Tucson, Arizona, 23-24 February 2000). The goals were to initiate relationships among members of the research and management communities, and begin to develop a common understanding of fire and climate variability and linkages.

Much of the workshop consisted of presentations by experts in climate variability and relationships to fire conditions. Interactions occurred informally and through work groups that were charged with responding to specific issues and questions. Group discussions were facilitated by workshop participants having a range of backgrounds, but generally they were not social scientists.

Participants included personnel from a variety of agencies with responsibility for managing or responding to wildland fire risks, as well as physical scientists involved in research of fire and climate modeling and prediction. Table 2.5 lists the affiliations of the workshop participants. Attendance included staff from agencies throughout the United States, and represented local, state, regional, and national jurisdictions.

National Workshop 2001

In 2001, the CLIMAS core office (B. Morehouse and G. Garfin, ISPE, UA) built on the relationships developed at the climate and wildland fire management workshop held in Tucson in the prior year. The office organized a three-day workshop for wildland fire managers and the climate research and forecasting communities (Fire and Climate 2001, ISPE, UA, Tucson, Arizona, 14-16 February 2001). The workshop was aimed at advancing the discussion, begun in the prior workshop, about the delivery, understanding, and use of climate information and forecasts.

Table 2.5 Affiliations of wildland fire management stakeholders participating in interaction events.

Participant Affiliation	Event A	Event B	Event C	Event D
Federal Interagency Groups				
National Interagency Coordination Center	X	X		
Northwest Interagency Coordination Center	X			
Southwest Interagency Coordination Center	X		X	
Eastern Great Basin Coordination Center		X		
Bureau of Land Management				
Southwest Strategy Fire Coordination Center	X			
Office of Fire and Aviation		X		
Regional Offices	X		X	
United States Forest Service				
Fire Sciences Laboratory	X			
Pacific Northwest Forestry Sciences Laboratory	X	X		
Fire and Aviation Management		X		
Interagency Fire Forecast and Warning Unit		X		
Southern Research Station		X		
Rocky Mountain Research Station			X	
Southwest Region		X		
Pike and San Isabel National Forests		X		
Coronado National Forest	X	X	X	
Other (not denoted)	X	X	X	
Other Federal Agencies				
United States Geological Survey	X	X		
United States Fish and Wildlife Service	X	X	X	
National Park Service (multiple units)	X	X	X	
Natural Resources Conservation Service				X
Bureau of Indian Affairs		X	X	X
NOAA[1] Climate Diagnostics Center	X	X		
NOAA[1] Office of Global Programs		X		
NWS[2] Climate Prediction Center		X		
NWS[2] Weather Forecast Offices (Phoenix, Tucson, Flagstaff, Arizona; Albuquerque, New Mexico; Salt Lake City, Utah)	X	X		

[1]NOAA = National Oceanic and Atmospheric Administration.
[2]NWS = National Weather Service.

Table 2.5, continued. Affiliations of wildland fire management stakeholders participating in interaction events.

Participant Affiliation	**Event**			
	A	**B**	**C**	**D**
State, Tribal, and Other Groups				
Western Regional Climate Center	X	X		
Florida Division of Forestry	X	X		
California Division of Forestry		X		
Alaska Fire Service		X		
New Mexico State Forestry Department	X			
Arizona State Land Department	X	X	X	
Arizona Division of Emergency Management			X	
Arizona Department of Agriculture				X
San Carlos Apache Tribe	X	X	X	
Yavapai-Apache Nation				X
White Mountain Apache Tribe				X
The Nature Conservancy			X	
SEMARNAT (Mexico)			X	
Universities				
University of Washington	X	X		
Scripps Institute of Oceanography	X	X		
Florida State University	X			
Desert Research Institute	X	X	X	
Prescott College	X			
UA[3] Laboratory of Tree Ring Research	X	X	X	
UA[3] Institute for the Study of Planet Earth	X	X	X	X
UA[3] Department of Hydrology and Water Resources	X	X	X	X
UA[3] School of Renewable Natural Resources				X
UA[3] Bureau of Applied Research in Anthropology		X		X
UA[3] Department of Geography and Regional Development		X	X	
UA[3] Office of Arid Lands		X		

[3]UA = University of Arizona.

An entire day was devoted to topics related to climate prediction and use of climate information by fire managers. As in the prior workshop, interactions occurred informally and through work groups that were charged with responding to specific issues and questions. Group discussions were facilitated by workshop participants having a range of backgrounds, but generally they were not social scientists.

In addition, a mini-workshop provided for detailed interactions addressing interpretation and evaluation of the CPC seasonal climate forecasts (Hartmann et al., 2001). It was a modified version of the Forecast Evaluation Workshop implemented for water managers. The mini-workshop included (1) a review of the different types of forecasts available, (2) explanation of the correct interpretation of climate forecasts and a hands-on exercise in forecast interpretation, (3) a discussion of forecast evaluation methods, and (4) some examples of evaluations of official CPC seasonal climate forecasts, with an emphasis on evaluations that could be useful for fire management. The mini-workshop elicited comments from stakeholders using focused discussion (Whyte, 1977; Rubin and Rubin, 1995) and min-surveys developed prior to the workshop.

At the beginning of the mini-workshop, participants were asked to divide into four groups: climatologists/meteorologists, fire planning, fire operations, and other (e.g., fire research). This was done to prevent climatologists from influencing the responses of fire managers and to allow fire managers an opportunity to interact with their peers. In order to check how well climatologists knew their "customers", they were asked to answer the mini-survey questions in terms of how they thought the fire managers would respond, rather than in terms of what they personally believed to be the correct answer.

Each time a question was asked, the climatologists were reminded to answer in this way. Training materials used in the mini-workshop are available from the author. The author facilitated the interactions, with the help of two physical scientists (T. Pagano and G. Garfin, Department of Hydrology and Water Resources and ISPE, UA) who helped answer questions that arose in the four groups.

Participants included personnel from a variety of agencies with responsibility for managing or responding to wildland fire risks, as well as physical scientists involved in research of fire and climate modeling and prediction. Some participants had also attended the workshop the prior year. Table 2.5 lists the affiliations of the workshop participants. Attendance included staff from agencies throughout the United States, and represented local, state, regional, and national jurisdictions.

Regional Workshop

The CLIMAS core office (B. Morehouse and G. Garfin, ISPE, UA) also organized a one-day workshop on wildland fire risks and climate variability that had a more local focus (Fire and Climate in the Southwest 2001, ISPE, UA, Tucson, Arizona, 28 March 2001). The workshop's goals included interactions with fire managers about sub-regional climate variability, climate forecasts for the upcoming 2001 fire season, and development of tools to enable incorporation of climate considerations into fire and resource management decisions.

Much of the workshop consisted of presentations by experts in climate variability and relationships to fire conditions. One presentation focused on interpretation of CPC seasonal climate forecasts and evaluations of their performance (Pagano and Hartmann, 2001). Interactions occurred informally and through work groups that were charged with responding to specific issues and questions. Group discussions were not facilitiated, but relied on self-motivated interaction of the group members, who had a range of backgrounds.

Participants included personnel from a variety of agencies with responsibility for managing or responding to wildland fire risks, as well as physical scientists involved in research of fire and climate modeling and prediction. Some participants had also attended one or more of the prior fire and climate workshops. Most fire managers represented agency units with local or state jurisdictions. Table 2.5 lists the affiliations of the workshop participants.

Bureau of Indian Affairs and Tribes Meeting

One member of the CLIMAS project (D. Austin, BARA, UA) had well-developed and ongoing relationships with members of several Native American tribes in the Southwest. Because of those relationships, several CLIMAS researchers were invited to participate in a meeting of the western region of the Bureau of Indian Affairs and affiliated tribes (Forestry and Natural Resources Meeting, Yavapai-Apache Nation, Camp Verde, Arizona, 6-8 March 2001). The purpose of the presentations was to introduce the CLIMAS project, present research about climate information and its use in resource planning and management, and conduct a mini-workshop on interpretation, evaluation, and use of the CPC seasonal climate forecasts.

The mini-workshop was conducted much like that for the Fire and Climate 2001 Workshop held at the UA earlier in the year. However, material was targeted toward people who were not necessarily familiar with CPC climate forecasts. A companion of "Southwest Climate in a Nutshell" (Pagano, 1999), "How Good are Climate Forecasts?" (Hartmann and Pagano, 2001), was prepared to help develop relationships, by providing material (with contact information) to take home and share with others. In addition, the hands-on activities were designed to be highly participatory. Probabilistic concepts were illustrated by using several sets of dice, with two sides labeled to correspond with the three tercile categories used in the CPC seasonal climate outlooks. Some dice were weighted to reflect shifted probabilities associated with non-climatologic forecasts. In small groups, participants rolled their assigned dice several times to observe that, even though some conditions were more likely (e.g., dry conditions associated with La Niña events), other conditions could still occur. In addition, mini-survey questions were answered by having participants move about the room to locations corresponding to potential responses.

Participants at the meeting were invited by the host organization. A list of all participants was not available from the organizers, but included representatives from a number of Native American tribes in the Southwest and Bureau of Indian Affairs staff. Participants included regional foresters, forest managers, and range managers. Organizations known to have participated in the meeting are listed in Table 2.5.

2.4 RESULTS

2.4.1 Issues of Concern to Stakeholders

Tables 2.6, 2.7, and 2.8 list topics and issues raised by water managers, ranchers, and wildland fire managers, respectively. Issues noted by stakeholders generally fell into five broad topics: (1) observations and data, (2) analysis, modeling, and forecasting, (3) forecast and information products, (4) communication and interaction, and (5) use of information and forecasts in decision making. Pagano et al. (1999, 2000, 2001, 2002) provide additional details about responses from water management stakeholders, while Hartmann et al. (2001) describe responses from one set of wildland fire managers. Articles are in preparation with CLIMAS colleagues presenting additional results for the ranching and wildland fire management sectors (see Section 1.4).

2.4.2 Mini-survey of Wildland Fire Managers I

Two of the workshops for wildland fire managers made use of mini-surveys as well as focused discussions. Results from first workshop are not representative of the broader fire management community, because participants were clearly interested in climate and had experience in interpreting forecasts. In addition, CPC forecasts had been presented and discussed frequently during sessions immediately prior to the mini-surveys, including some that focused specifically on the most recent CPC forecasts in the context of the coming fire season (Wolter, 2001; Cayan, 2001; Westerling, 2001; LeCompte, 2001). Finally, some participants (members of the "other" category) were

Table 2.6. Hydroclimatic topics and issues raised by water management stakeholders.

Topics and Related Issues
Observations and Data
Desire observations about additional precipitation details (e.g., storm intensities, areal extent)
Need better estimates of precipitation, snow accumulation and ablation
Radar data are not very useable
Need to tie new data types and data sets to older information (e.g., rain gauges and radar)
Lack of data for Salt River Basin on Apache tribal lands
Analysis, Modeling, Forecasting
How good are the reconstructed naturalized streamflow records?
Need to evaluate performance of seasonal climate and water supply forecasts, for various seasons, lead times, locations, including nesting of short- and long-term forecasts
How can measurements of snowpack conditions be incorporated into water supply forecasts?
How can seasonal climate forecasts be incorporated into water supply forecasts?
Want researchers to "go the extra step", put results and models into useful forms and tools
Need better understanding of error characteristics of precipitation estimation
Need to determine relationship between climate, water resources (especially base streamflows), and water demand (e.g., northern Arizona, along Mogollon Rim)
Need explanation of the causes of variability seen in paleoclimatologic records and comparison to current causes of variability
Forecast and Information Products
Need predictions of extreme events
Need categorical probability forecasts to be transformed into probability distributions and summary statistics
Confusion and misunderstanding about forecast procedures and interpretation (e.g., reliance on statistical rather than dynamical models in forecasts, use of "climatology in climate forecasts)
Too much information: need guidance on what information and products are good or not good
Communication and Interaction
For civil engineers, need more effective communication about implications for water supplies of long-term climate variability and non-stationarity indicated by paleoclimatologic records (e.g., tree rings, paleo-floods)
State Association of Floodplain Managers would be good forum for interacting with water management sector about hydroclimatic forecasts and non-stationarity issues
There is some feedback between forecasters and users (e.g., NRCS[1] surveys), but needs to happen more extensively and include research and funding agencies as well
Use in Decision Making
Some decision makers have little flexibility in use of new products due to regulatory requirements that specific information be used (e.g., in reservoir regulation)
Institutional factors limit ability of communities in upper Salt River Basin from mitigating impacts of hydroclimatic variability (e.g., through Arizona Corporation Commission)
Decisions based more on "fear of failure" than "prospects for success"
Some engineering infrastructure based on summer storm intensities
Engineers working at local scale (e.g., five acres) need link between regional and local conditions
Civil engineers will not use paleo-climatologic records unless scientists can demonstrate that climate processes and forcing conditions are similar to those of the present

[1]NRCS = Natural Resources Conservation Service.

Table 2.7. Hydroclimatic topics and issues raised by ranching stakeholders.

Topics and Related Issues
Observations and Data
USGS[1] use of rolling mean makes it more important to know the relevant historic period. Adding or dropping a single extreme year can change values significantly (e.g., 25%).
Some ranchers have long records of precipitation (e.g., from 1930s) at different locations within their ranch (e.g., different elevations), that they would like to see integrated into databases.
Gila River NRCD[2]: climate has changed. Summer, clouds used to bring rain, but now bring big dust storms. Gila River was perennial, but now is always dry.
Analysis, Modeling, Forecasting
Use ranchers' local meteorologic records to improve high-resolution areal interpolations
How good are climate forecasts, for different regions, seasons, and lead times?
Local-scale analysis, modeling, and forecasting of more interest than regional-scale products
Forecast and Information Products
Cloudiness and winds would be important new products, because evaporation can rapidly negate the effects of even high rainfall if conditions are right (e.g., hot, windy, no clouds)
Desire plots of near real-time conditions with their historical context
Current climate forecasts difficult to relate to without some connection to quantities (e.g., total precipitation) or likelihood of extreme events
What are climate conditions forecast for the next 5-10 years?
What are the interannual and seasonal trends and variability of groundwater supplies and recharge? How are groundwater levels related to seasonal precipitation variability?
Does cloud seeding work?
What are the impacts of dams and dam removal on water supplies and the environment?
What does the tree ring record show about flows in the San Pedro River over hundreds of years?
Need clear, unbiased information about global climate change (i.e., what is known or not known)
Communication and Interaction
Considerable confusion over interpretation of Climate Prediction Center climate forecasts
Personal interaction is important (i.e., not just websites, brochures, or videos)
Detailed information was appreciated more than general information obtainable elsewhere
Some NRCDs have popular websites (e.g., Verde), but no need for each district to have one
Many regional meetings provide opportunities for interaction with ranching stakeholders (e.g., Verde River Days, Southwest Indian Agricultural Association). Interaction with Navajo should be through the tribe. Hopi and Gila River interactions through the tribe or NRCDs[2].
In some locations, cooperative extension would be effective avenue for interaction because they are active in the community and well respected
Good frequency for interaction varies: e.g., monthly for Gila River NRCD[2], 4 times/year for Navajo Mountain NRCD[2]
Use in Decision Making
How can we create emergency drought management strategies?
Fear forecasts will be used by land management agencies to force changes on ranchers
Intergenerational ranches considered to have more resources and options for adapting to variable circumstances
Important issues: floods, drops in groundwater levels and riverine base flows, land development pressures

[1]USGS = United States Geological Survey.
[2]NRCD = Natural Resources Conservation District.

Table 2.8. Hydroclimatic topics and issues raised by wildland fire management stakeholders.

Topics and Related Issues
Observations and Data
Need to track forecasts and fire activity in corresponding periods
What are the limitations on the quality of down-scaled data?
Analysis, Modeling, Forecasting
Quantitative connections between climate variability and fire conditions limited by poor quality of fire data
Relevant scale varies by region (e.g., larger scale in Southeast, highly localized scale in Pacific Northwest)
Priority of forecasts: highest priority is synoptic for all regions, then interannual (i.e., El Niño-Southern Oscillation) for most regions, but interdecadal (i.e., Pacific Decadal Oscillation) for the Pacific Northwest
What variables can be predicted beyond temperature and precipitation?
How good are climate forecasts, for different regions, seasons, and lead times?
Forecast and Information Products
Need for products targeted at different management levels and responsibility: field staff to upper management, operations to planning
Monitoring information (e.g., 1km^2 drought index) can be as important, or more so, than forecast products
Need "better" packaging and presentation
Discontinuities of information at boundaries of climate divisions and weather forecast zones create problems
Need primer on climate variability and critical climate patterns for different regions
Desire web-based products that provide easy access to spatially organized information, basic climate information, one-stop shopping, frequently asked questions, opportunities for feedback, e-mail notices and updates
Development of scenarios could assist consideration of climate non-stationarity
Need better descriptions of models and their output, including strengths and limitations
Need guidance on what information and products are good or not good
Would like to be able to place present conditions in different historical contexts (e.g., 30-year climatology, period of record, paleoclimatological data)
Communication and Interaction
Could benefit from working with other sectors (e.g., water management)
Recurring interaction is recommended
Implement regional courses and other training for fire managers about climate variability, linkages to fire conditions, and forecast products
Take advantage of climate events to promote interactions and training
How can the climate research community manage expectations (i.e., preclude decision makers from expecting more than can be delivered)?

Table 2.8, continued. Hydroclimatic topics and issues raised by wildland fire management stakeholders.

Topics and Related Issues
Use in Decision Making
Decision makers have flexibility to incorporate different information and products of their choosing
Need better understanding of institutional barriers to use of climate forecasts and information (e.g., current budget schedules, limitations of planning horizon being limited to fiscal year)
Need bureaucratic environment open to demonstration projects showing use and value of climate forecasts
Some meteorologists skeptical about importance of climate issues for decision making
Need to address how to handle forecast uncertainty
Some decisions linked to other sectors (e.g., water management)
Potential use of climate forecasts for fire/environment rehabilitation projects (e.g., locations, species, timing)
Climate information and forecasts affect decisions to let natural fires burn without suppression
Use is tied to proper timing of issuance of products
Need to identify critical conditions and decision points where forecasts and monitoring information would have the most impact
Need to consider climate non-stationarity

seated in the back of the room and may not have been able to adequately see some forecasts, particularly forecasts issued by the International Research Institute (IRI) for Climate Prediction.

Each of the four functional groups (i.e., climatologists/meteorologists, fire planning, fire operations, and other) were asked about their preferences concerning forecast format attributes and ancillary information. After all options were presented, participants were allowed to discuss the options within their group, and then were asked to indicate their group's choice on a large easel. In some cases, individuals within a group could not reach consensus on their choices and were allowed to make dual choices. Because of the small number of groups, results are only summarized in Table 2.9 to indicate general preferences.

In addition, participants were asked to respond individually, on index cards collected at the end of the survey, to a series of questions focused on forecast interpretation and terminology. Table 2.10 presents results for those questions. The first question concerned the interpretation of forecast probabilities. While looking at a CPC forecast map for precipitation for January-March 2000 (issued in December 1999), participants were asked to write down their answer to the question "What is the forecast for Tucson, Arizona?" The forecast legend was not shown, because it is often left out when non-NWS organizations provide CPC forecasts. The map indicated there was a 53-63% probability that Tucson would be in the driest tercile of the 1961-1990 historical record, a 33% probability it would be in the middle tercile and a 3-13% chance of being

Table 2.9 Preferences for forecast formats and ancillary information based on questions posed at the 2001 fire and climate workshop. Results based on responses from four groups: climatologists/meteorologists, fire planning, fire operations, and other (e.g., fire research).

Forecast Format: preferred alternative listed in bold[1]	
Option 1	Option 2
Uniform confidence intervals[2]	**Targeted confidence intervals**[3]
Sharp confidence interval boundaries[2]	**Gradual confidence interval boundaries**[3]
Flexible probability intervals[2]	**Fixed probability intervals**[3]
Two forecast categories (above/below)	Three forecast categories (above/normal/below)[2,3]
Always forecast something	Forecast only when confidence warrants
Ancillary Information	
Crucial Information	Information Nice, But Not Necessary
Historical Context	*Historical Context*
Recent conditions	Conditions from other periods
Analog conditions (e.g., El Niño periods)	Paleoclimatological conditions
Conditions over entire period of record	
Forecast Rationale	*Forecast Rationale*
	Which techniques controlled the forecast
	What conditions drive the forecast probability statement
Past Forecast Performance	*Past Forecast Performance*
Performance of official forecasts	Performance of specific forecast techniques

[1]No option listed in bold where groups expressed conflicting preferences.
[2]Similar to the forecast format used by the International Research Institute for Climate Prediction.
[3]Similar to the forecast format used by the Climate Prediction Center.

Table 2.10 Responses to mini-survey questions asked at 2001 fire and climate workshop. Correct answers indicated in gray. Entries show number of responses for each category, among each class of users. Total number of users in each class = n.

Question 1: "What is the forecast for Tucson, AZ?"					
Response framed in terms of:	Planning (n=6)	Operations (n=7)	Other (n=8)	Total Fire[1] (n=21)	Climatologists & Meteorologists (n=15)
Categorical and "correct"	5	6	6	17	10
Categorical and "incorrect"	0	0	0	0	1
Probabilistic and "correct"	0	1	1	2	2
Probabilistic but "incorrect"	0	0	0	0	0
Deterministic	0	0	0	0	0
Other	1	0	1	2	2
Question 2: "What is the forecast for Reno NV?"					
Normal/Average	5	3	4	12	8
Climatology/Total uncertainty	0	1	3	4	7
Other	1	3	1	5	0
Question 3: After seeing the legend: "What is the forecast for Tucson AZ?"					
Answer already correct	0	1	1	2	2
Kept incorrect answer	3	1	5	9	7
Changed from categorical to probabilistic	1	3	1	5	4
Other	2	2	1	5	4
Question 4: After seeing the legend "What is the forecast for Reno?"					
Answer already correct	0	1	3	4	7
Kept incorrect answer	4	2	3	9	8
Changed to climatology	1	2	0	3	1
Other	1	2	2	5	1
Question 5: "According to this forecast, which will be wetter, Tucson or Florida?"					
Florida	0	4	2	6	4
Arizona	4	2	2	8	7
Neither*	1	1	4	6	4
Other	1	0	0	1	0
Question 6: With respect to the CPC seasonal outlooks, how is "dry" defined?					
Below Mean/Less than Normal	1	6	3	10	10
Reference to terciles	0	0	0	0	1
Less precipitation, other form	4	1	3	8	4
Other	1	0	2	3	0

[1]"Total fire" represents all non-climatologists.

Table 2.10, continued. Responses to mini-survey questions asked at 2001 fire and climate workshop. Correct answers indicated in gray. Entries show number of responses for each category, among each class of users. Total number of users in each class = n.

Question 7: How does IRI define "dry"?					
Response framed in terms of:	Planning (n=6)	Operations (n=7)	Other (n=8)	Total Fire[1] (n=21)	Climatologists & Meteorologists (n=15)
Same, incorrect answer as for CPC	4	1	4	9	7
Reference to terciles	0	0	0	0	1
Different from CPC and incorrect	1	6	1	8	5
Other	1	0	3	4	2

[1]"Total fire" represents all non-climatologists.

in the wettest tercile of the record. The responses were categorized into six different classes: (1) categorical and "correct" (e.g. "warm and dry", "below normal precipitation", "dry, less precipitation"), (2) categorical and "incorrect" (e.g. "above average precipitation"), (3) probabilistic and "correct" (e.g., "greater likelihood of dry", "48% chance it will be drier than normal"), (4) probabilistic but "incorrect", (5) deterministic (e.g., "48% of normal"), and (6) other (e.g., "wetter than normal temperatures", "drier by three units of some kind").

The second question concerned interpretation of the designation "CL" or "climatology". While looking at a CPC forecast map for precipitation for the winter 1999-2000, participants were asked, "What is the forecast for Reno, Nevada?" The forecast legend was also omitted for this question. The map showed this area having a "CL" designation, meaning that there was total forecast uncertainty, forecasters had zero forecast confidence, or that forecasters considered all conditions equally likely. The responses were classified as (1) normal (e.g., "near normal", "normal"), (2) climatology (e.g. "no skill", "no forecast", "climatology"), and (3) other (e.g., "nothing significant forecasted", "slightly above normal").

The third and fourth questions evaluated the impact on interpretive correctness of having the forecast legend available. After making the CPC legend available, questions one and two were repeated. Participants responded in several ways: (1) they kept their previous correct answer, (2) they kept their same, but incorrect, answer, (3) they changed from a categorical to a probabilistic forecast (e.g., "53-63% chance of below normal", "10-20% chance of below normal, "there is a 10-20% probability anomaly"), or (4) they gave some other answer, usually mistaking a probability anomaly for a “percentage of normal” forecast (e.g., “10-20% below normal precipitation”, “below”, “43.3-53.3% [no units]”, “precipitation 50% below normal”).

Questions five through seven concerned the various definitions of "wet" and "dry" used in CPC and IRI seasonal climate forecasts. For question five, using the same CPC map, participants were asked to compare the forecasts for Tucson and central Florida in answering “Which do you think will be wetter, Tucson or central Florida?” The probability anomalies were stronger in Florida than in Tucson, but Florida is generally a wetter place. The correct answer is that one does not know. The CPC maps cannot answer the question for two reasons: (1) they do not forecast rainfall quantities, but only the probability of precipitation falling in one of three categories, and (2) the definition of dry is relative to the location and season. There were four types of answers: (1) Arizona will be wetter, (2) Florida will be wetter, (3) neither or can’t tell, and (4) other (e.g., one respondent gave a probabilistic forecast for Florida).

For question six, participants were asked, "What is the CPC definition of dry?" CPC takes a 30-year historic period, ranks those years from wettest to driest and then divides that list into three parts with 10 years in each category. The wettest 10 years are considered “wet”, the driest 10 years are considered “dry”, and the other 10 are considered normal. When CPC forecasts a higher probability of dry conditions, they define dry by using the driest 10 years of the 30-year record. Responses fell into four categories, in which “dry” is defined as: (1) below mean or less than normal, with no other quantities identified, (2) conditions falling in the lowest tercile (e.g., “lowest third"), (3) less precipitation, but in some other form (e.g., "10-20%", "lesser degree of precipitation", "predicting no precipitation", "drier has meaning, dry has none", "5-10% below normal"), and (4) other (e.g., blank, "don't know).

For question seven, participants were asked, "How does IRI define dry?" IRI and CPC have the same definition of dry, although their forecast map formats are significantly different. One climatologist was uncertain whether the question referred to the terciles or IRI's special designation of "dry season", which appears as a gray region labeled "D" on the IRI maps. IRI uses "dry season" to indicate that less than 15% of a region's annual precipitation usually falls during this particular 3-month period; the question did not refer to the "D" on IRI maps. There were four categories of answers: (1) the same as the answer given for CPC, but incorrect (e.g., "below mean"), (2) the correct interpretation, which is "in the lowest tercile", (3) a different answer than the one given for CPC, but still incorrect (e.g., "lack of moisture", "less than 75% of normal", "8% or more probability of being dry", "dry outside mean with confidence interval"), and (4) other (e.g., blank, "don't know").

2.4.3 Mini-survey of Wildland Fire Managers II

The second survey investigated what qualities of seasonal climate forecasts that land and fire managers considered important. Participants in this survey had generally not had much exposure to CPC forecasts prior to the workshop. The questions were asked at the end of the workshop presentation, which included discussion and demonstration of

Table 2.11. Responses to mini-survey questions asked at the Bureau of Indian Affairs and Tribes meeting. Entries show number of responses for each category. Total number of users in each class = n.

Question 1: A climate forecast is bad if an event was given a low chance of occurrence, but then it actually happened.				
Strongly Agree	Agree	Don't Know	Disagree	Strongly Disagree
0	6	12	7	0
Question 2: In climate forecasts, a low rate of incorrect forecasts is more important than a high rate of correct forecasts.				
2	13	1	0	9
Question 3: It is more important to know that a "climate event" in not likely to happen, than to know that a climate event is likely to happen.				
0	6	13	3	3
Question 4: Climate forecasts are not useful unless they show a strong chance for an event to occur.				
0	0	15	10	0
Question 5: To be useful, a climate forecast probability must be at least what percentage?[1]				
33-39%	40-49%	50-59%	60-69%	70% or greater
8	3	3	6	4

[1]Base probability is 33%. Where a range of values was given, the minimum acceptable percentage is used.

different aspects of forecast performance. Table 2.11 presents the results for each question. Results showed a diversity of responses, although the choice "don't know" was the largest response overall. That response could have occurred in two ways: (1) when a participant did not understand the question or (2) if a participant did not know how they felt about the question. More importantly, however, participants' selection of other options indicates that at least some individuals were able to make connections between various forecast attributes and implications for their specific decision making context.

2.5 DISCUSSION

As described above, there have been many interactions with stakeholders related to hydroclimatic information and products during 1998-2001. These interactions provide insights about stakeholder situations and perspectives along several lines: (1) use of hydroclimatic information and forecasts, (2) the organization of stakeholder interactions, and (3) the conduct of stakeholder interactions.

2.5.1 Stakeholder Use of Hydroclimatic Information and Forecasts

Perspectives about Hydroclimatic Variability

Generally, individuals with training in hydroclimatology and agencies with internal expertise had the best understanding of processes. However, stakeholder perspectives about hydroclimatic processes and variability differ as much within a single sector as across different groups. Some emergency managers in small communities appeared to have poor understanding, while some tribal members had excellent understanding. For example, one Navajo elder could describe in detail how he knows when the monsoon season has arrived (winds shift to become easterly) and when the dry season returns (winds become westerly) in ways that are consistent with climatological definitions. Often, people were familiar with the terms "El Niño" and "La Niña", but had only vague ideas about what physical processes were involved. That variations in ocean temperatures can affect Southwest climate conditions is consistent with Hopi traditions. Moodie and Hadley (2001) describe how ranchers' perspectives of climate variability relate to decisions about ranch operations and strategic planning.

Perspectives about Climate Forecasts

Uniformly across stakeholder groups, individuals were often uninformed or had mistaken impressions about the seasonal climate forecasts issued by the CPC. Even hydroclimatic researchers were confused about some aspects of the CPC forecasts. Results from the mini-surveys administered to fire managers exemplifies several of the issues. Notably, the fire managers do not view the current generation of forecasts in probabilistic terms. The most common misinterpretations of the CPC forecasts are that the contours indicate the severity of conditions expected and the "CL" or climatology designation represents a forecast for normal conditions. For individuals who interpret the CPC forecast maps as categorical forecasts (i.e., conditions will be like those indicated, with implied certainty), maps with contours showing weak probability statements (e.g., 5-10% probability anomalies) can be dangerous, especially when they are the strongest statement on a map. In addition, some users may interpret forecasts for their region relative to the rest of the country, without considering regional variations in the climatologic distribution of conditions; this problem is particularly relevant when forecasts do not receive media attention or significant agency outreach efforts, e.g., when conditions do not concern El Niño or La Niña events.

In addition, there were divergent interpretations of CPC's definition of fundamental terms such as wet, dry and normal. The base period (1961-1990) was rarely considered in discussions when a CPC forecast was presented. Likewise, some users were unaware that terciles were being used; many interpreted the forecasts as simply for above normal or below normal conditions without reference to a third, near-normal category. Users with improper definitions of forecast categories (e.g., dry means "predicting no precipitation") or climatologic conditions (e.g., warm means "similar to the past five years" rather than all of 1961-1990) have a greater potential to be disappointed by, and ultimately skepical of, the forecasts. This is particularly relevant for temperature forecasts, which have been strongly influenced by conditions throughout the 1990's being frequently warm relative to the period 1961-1990.

However, users could be surprisingly sophisticated in their consideration of the probabilistic forecasts. For example, when shown the CPC climate forecasts, one group of ranchers asked, unprompted, how the tercile categories were determined, what the base probabilities were for each category, and how probabilities were shifted from other categories to the "most likely" category. They initiated discussion about using reduced likelihoods in their decisions, how strong forecast statements had to be in order to have utility, and the role of climate futures in hedging their operations.

Important Climate Variables, Seasons, Lead Times, Forecast Performance

Discussions with stakeholders from the water resources management sector revealed that the periods especially important to them were concerned with water supplies that originate primarily as mountain snowfall. In the Southwest the relationship between winter precipitation and water supplies is particularly strong because late spring and early summer have little additional precipitation. Typically, in October, regional-scale water management agencies meet with forecasters at the NWS Colorado Basin River Forecast Center (CBRFC) to review potential winter and early spring conditions that will ultimately affect seasonal water supplies. The water managers track seasonal water supply forecasts issued throughout the winter; Chapter 5 describes specific forecast seasons and lead times relevant to these stakeholders. While rains associated with the summer monsoon typically have little impact on useable water supplies in larger basins, their transient local effects are important for stakeholders (e.g., irrigation districts) that augment rainfall with contracted water deliveries or groundwater pumping.

Ranchers tended to be more variable and flexible in their decision making schedules. However, some ranchers were able to identify specific conditions and periods of time routinely important to them. In southeastern Arizona, ranchers graze their cattle in the uplands during the winter and in the valleys in the summer. Forecasts issued in October and November, covering December through March are of interest, and could be especially important for February and March. Winter rains increase noxious weeds, but are perceived as good for replenishing water supplies; cold conditions are problematic, while warm winter conditions are advantageous. In addition, forecasts issued in May and covering June-September could be useful; ranchers require a minimum of six to seven inches of rain during the core monsoon months of July and August to ensure good grass production. Ranchers in central Arizona generally feed, rather than graze, their cattle, so forecasts are less important for production decisions. However, forecasts of drought conditions for any season and even for other regions could help them time their cattle sales to exploit higher prices. In northern Arizona, ranchers rely on cool season grasses, but growth can be impaired by one week of cool temperatures in the spring or autumn that can take several weeks to overcome. Dry conditions are more problematic than wet, to the extent that ranchers would rather experience false alarms about potentially dry conditions rather than be surprised by their occurrence. The worst situation would be to make decisions based on forecasts favoring wet conditions, but having conditions actually turn out to be dry.

The specific seasons of interest to fire management agencies depend on the climate, elevation, and land cover types within their area of jurisdiction. Low-elevation grasslands can be at high risk throughout a dry winter, while high elevation forests have a later fire season. Thus, the important seasons for fire managers in the Southwest are highly variable due to the tremendous topographic and land cover variation. Fire risk is also highly conditioned on prior climatic conditions. Important event sequences include the second dry winter after a wet winter and a dry summer following a dry winter. Regional fire managers submit their requests for seasonal resource needs to national headquarters in March, regardless of their actual fire season. Thus, fire managers are restricted to using forecasts issued January-March, covering all subsequent seasons, to determine their request for fire crews and equipment.

Use of Forecasts in Decision Making

A few stakeholders have clearly made beneficial use of hydroclimatic forecasts over the past several years. However, many stakeholders have not. Pagano et al. (1999, 2000, 2001, 2002) discuss at length the use of hydroclimatic forecasts by water managers and their comments are not repeated here. Ranchers operate much like emergency water managers in that they consistently attempt to reduce their vulnerability, although for drought rather than flooding. An oft repeated mantra was, "Prepare for the worst, hope for the best". One rancher provided a more specific description of this approach, "Better to always plan for drought. Better to be understocked than overstocked. Better to keep a young herd than an old herd. Better to develop as much water supply as possible." In addition, ranchers with sufficient financial resources stated they were willing to buy extra hay in October, because if it was not needed for that winter, they could store it for up to five years with adequate moisture protection. Fire managers are constrained in their use of hydroclimatic forecasts by the bureaucratic budgetary schedule. Fire managers envisioned that, with increased administrative flexibility, prescribed burn programs could potentially be planned months in advance, although actual implementation would be subject to the vagaries of the weather. Resources could be shifted (nationally and locally) to dramatically increase burn programs where climate forecasts and existing field conditions indicated ideal opportunities.

While stakeholders in the three sectors clearly differ in the specific opportunities for using hydroclimatic forecasts in their planning and operations, there were also clear commonalities in the constraints that limit the usability of forecasts across all groups. All groups indicated that the lack of ongoing and readily available monitoring of forecast performance limited their confidence and consideration of forecasts. Uniformly, stakeholders understood the difference, and the implications for decision making, between making a forecast for "normal" conditions and withholding of a forecast statement due to total uncertainty. In addition, seasonal forecasts at regional-scales were less usable for most stakeholders, across all groups, than forecasts of events at local scales. Stakeholders in two of the three sectors indicated that forecasts would be more useable if accompanied by more visible historical information. Finally, two sectors expressed difficulty with information overload and their inability to distinguish between "good" and "bad" information and forecast products.

2.5.2 Organization of Stakeholder Interactions

Interactions that Enable Qualitative Analyses

The essential limitation of all the interactions described herein is the inability to develop quantitative relationships (Whyte, 1977; Mohr, 1982, 1999). However, the limitation is nonproblematic, because throughout, the goal was to identify and understand stakeholder relationships to hydroclimatic variability, information and research, not to develop econometric or quantitative models. The advantages of the various approaches described herein derive largely from their focus on contextual details. In contrast to quantitative approaches (e.g., survey questionnaires), qualitative analysis brings to light the complexities - predicaments, tradeoffs, strategies - behind what otherwise would be simply statistical outcomes (Schoenberger, 1991). Further, by enabling identification of commonalities, this focus aids the valid transfer of results to other situations (e.g.,other regions, stakeholders). In contrast, reliance on sampling strategies and standardized questionnaires (e.g,. Changnon, 2000a) to justify transferring results to other situations can be misplaced. The diversity and continuing evolution of conditioning variables (e.g., stakeholder objectives, mandates, resources; prior hydroclimatic events and consequences) confound determination of useful encompassing populations and sufficient random sampling (Mohr, 1999). Finally, most of the interactions described herein concurrently educated the stakeholders, as advocated by the National Research Council (1999b).

Diversity of Interactions

Although the author's interactions were initially intended to focus on stakeholders from the water resources management arena, there were benefits to engaging with ranching and wildland fire management stakeholders (who could be placed in a hydrologic context by considering them as watershed managers). Consistent messages from multiple sectors suggest broad applicability of any efforts to address identified issues.

Even though some results were consistent across sectors, the variation of stakeholder characteristics suggests that researchers should be flexible in the design of efforts to engage stakeholders and communicate information. For example, there was tremendous variation within the ranching sector alone. One ranching operation had staff with graduate training at Ivy League schools and used ultralight aircraft to herd their stock and monitor the range. Other operations had less than 10 animals and not much training or resources effectively manage their stock, but kept their animals out of a sense of tradition. NRCD agents distinguished between "progressive" ranchers and "non-managers". In the view of one NRCD agent, "progressive" ranchers will try new technologies and approaches, but the "non-managers" will not, because they don't make the connection between management practices, range conditions, and profitability.

Researchers should be flexible about where stakeholder interactions occur. For stakeholders that may be skeptical of, intimidated by, or too distant from universities, researchers should make use of opportunities to interact with stakeholders in setting that are more trusted, familiar, or nearby. State and regional meetings for specific sectors or stakeholder groups were often recommended. Standard sessions at scientific meetings do not allow enough time for in-depth discussion of issues. More flexible meeting structures are required, including panel or roundtable discussions, work groups, or mini-workshops.

Iterative Nature of Interactions

Outreach educates stakeholders and helps establish a common language for subsequent interactions. Soliciting input from stakeholders can engender support for scientific research, to the extent that subsequent research is responsive to stakeholder comments. In addition, the bi-directional interaction can increase the mutual respect between stakeholders and scientists, as scientists acknowledge that stakeholders have valued information and perspectives and by being responsive to stakeholder input. On the other hand, poor interactions (e.g., arrogant, non-responsive) can be counterproductive, not necessarily for the scientists responsible, but for researchers that may initiate interactions later and for the general science enterprise.

The role of iterative interactions in affecting stakeholder perceptions of research is illustrated by the experience with ranchers. At one large NRCD meeting, a rancher had completed a survey questionnaire for CLIMAS researchers nearly a year before. He pointedly asked what CLIMAS had done with those surveys. An explanation was given about how that input had shifted the CLIMAS research focus to forecast evaluation, in ways that could accommodate the aspects important to his operations. Further, other CLIMAS scientists were working on downscaling regional precipitation estimates to local scales. His demeanor, and that of the group, changed considerably. Subsequently, there was an extended conversation about how some ranchers have long-term precipitation records collected over generations and for different elevations. Many ranchers were interested in contributing that data to CLIMAS researchers. On the other hand, another group of ranchers had strong skepticism about university research programs and questioned the longevity of the CLIMAS project and its reliance on short-term funding cycles. These ranchers had been involved in prior university projects where promises were made, funding "dried up", and the ranchers never heard any thing more. While these particular ranchers would be an excellent group for testing of new climate products and forecasts, they want assurances that their time away from their ranch operations will have eventual benefits for them.

For all stakeholder sectors, discussions advanced to greater levels of complexity and reflection when the stakeholders were engaged a second time. This was particularly true at the November 2000 workshop for water managers and the Climate and Fire 2001 workshop for fire managers because many participants had attended the prior year's workshop as well. Presentation of forecast performance evaluations resulted in decidedly more sophisticated discussion of the potential use of probabilistic forecasts compared to presentations about climate variability. Interactions with ranchers changed as the hydroclimatic research and forecast assessments progressed. Even though different groups were engaged, it was still possible to obtain feedback about findings and products. However, that approach limited the ability to directly demonstrate to specific stakeholders that the CLIMAS program had responded to their specific input.

2.5.3 Conduct of Stakeholder Interactions

Insights for Effective Interactions

Productive engagement with stakeholders takes time. Especially with stakeholders not often involved in interactions with researchers, discussions planned for 20 minutes invariably stretched to an hour as participants became engaged and offered comments. For hands-on activities, two or even three hours seem to be required to allow time for people to integrate new or complicated concepts (e.g., probability, interpretation of forecasts) and begin to explore ways to incorporate products and information into their decision processes. This was as true across all stakeholders, from self-taught ranchers to water managers with advanced degrees.

Researchers should be prepared to face skepticism about university experts. Being introduced as "an expert on climate change from the University" evoked substantial skepticism, and even antagonism, at one meeting with ranchers. On the other hand, stakeholders appeared more trusting, as evidenced by the nature and extent of subsequent dialogue, when the physical scientists were introduced more humbly (e.g., as a student who had been studying these subjects for their research). It appears that some stakeholders associate researchers involved with climate change research to have underlying motives, while they consider students unbiased. However, with few exceptions, even the skeptical stakeholders valued the opportunity for personal interaction with scientific researchers. They also appreciated presentation simple in style that conveyed frugality with public funds (i.e., a simple photocopied handout rather than a published brochure or booklet).

Researchers should search for creative ways to engage stakeholders and solicit their input. Hands-on activities worked especially well. Use of the climate forecast dice, answering survey questions by moving around the room, and mini-surveys all worked well to generate interaction among presenters and participants. From a broader perspective concerned with maintaining engagement over time, some stakeholders also mentioned they would be interested in reviewing project documents and attending workshops targeted at reviewing project progress or products.

Researchers should acknowledge stakeholder expertise. This was especially important when interacting with ranchers. With tribal NRCDs, statements of respect for and acknowledgement of the ranchers' traditional knowledge and their relationships with the land and resource management agencies were important.

Researchers should be sensitive to their use of terminology. Some stakeholders liked the use of the terms "El Niño" and "La Niña", while others did not. In particular, one Native American rancher wanted to use the terms "warm ocean" and "cold ocean" because they were more explicit in their meaning than "El Niño" and "La Niña". Use of the term "climate change" can cause difficulties in communication; the terms "climate variability" or "year-to-year climate change" were received much better and led to more productive dialogue.

When interactions occur in non-traditional settings (e.g., agency offices, community buildings) researchers should be prepared for any contingency, including lack of a projector (bring several handouts), lack of a projector screen (bring a sheet, tape, and tacks), and even lack of convenient electrical outlets (bring a long extension cord and adapter).

Stakeholder Sensitivity: An Example

Some stakeholders were quite sensitive about how the interactions were conducted. For example, at one NRCD, most of the meeting was conducted in a Native American language. When preparing to use a projector for making the presentation about climate variability, there were pointed comments that a "white" screen was not available because we were not in the "white" world. Near the end of the presentation, after showing climate forecasts for the upcoming season, a respected tribal elder said that it was bad to talk about what the weather and climate might be like; weather and climate conditions depended on the right people performing ceremonies. I turned off the projector, stressed that it was good that the CLIMAS project learned their perspective, and did not want to offend them further or waster their time. The NRCD agent, also a tribal member, explained that in making forecasts, "five-fingered people" (humans) are saying they are as important as the deities. He addressed the group, saying that perhaps the younger generation neglects their ceremonies and traditions too much, but that they are trying to earn a living with their ranching and need all the information they can obtain. He finished by saying it would be good to stress that the tribal and forecast perspectives are compatible. The group, including the elder, then spent over 30 minutes talking about climate variability, including mention of forecasts. After the presentation was over, when the "Climate in a Nutshell" information packet was offered, everyone took a packet, including the elders. Later, a younger rancher told me a "joke" about how a group of ranchers would go to a specific elder each day to find out what the weather would be like that day. One day the ranchers asked, "What will the weather be like today?". The elder replied, "I don't know. I haven't watched the TV yet." The message was that even the traditionalists are interested in, and will use, advanced technology.

2.6 CONCLUSIONS AND RECOMMENDATIONS

2.6.1 Organization of Stakeholder Interactions

The public participation model (Figure 2.4) appears to be an effective approach for iterative bidirectional stakeholder interaction in the hydroclimatic research context of the CLIMAS project. Targeted engagement of stakeholders allowed discussions to be highly focused and in-depth, while engagement of diverse stakeholders allowed identification of cross-cutting issues that have broad applicability. Iterative interactions based on the response of research activities to stakeholder input enabled advances in the complexity of dialogue about hydroclimatic issues.

Effective stakeholder interaction requires sustained interactions. Once interaction has begun, there should be programmatic commitment to return to stakeholder groups to show results or how their input made a difference in the research. The timing of iterative engagements will depend on research progress, but should also be flexible to take advantage of "natural" opportunities (e.g., regular meetings of stakeholder groups). Funding of stakeholder driven research programs should be sufficient to fund travel to visit remote stakeholders. In addition, there should be a pool of readily available funding for interactions that can exploit unique, but short-lived, opportunities. Interactions with water resource management stakeholders, related to the 1997/98 El Niño event, benefited crucially from funding that was available on short notice, without having to go through an agency proposal process.

2.6.2 Improving Usability of Hydroclimatic Information and Forecasts

Fundamental work on formatting and communicating hydroclimatic information and forecasts remains to be done. The in-depth interviews and mini-surveys used for structuring interactions with water managers and wildland fire managers, respectively, provide starting points for more formal assessment of the following:

- formats that enable proper interpretation,
- format and content of historical contextual information,
- connection of forecasts to relevant conditions (e.g., local-scale events),
- forecast evaluations,
- accessibility of information, and
- information about the quality of information.

Efforts to produce or provide "one-size-fits-all" products are misdirected. Users have such different needs that the emphasis must be on how to provide a broad and flexible diversity of products.

Clearly the utility of the hydroclimatic forecasts is enhanced when forecast users, producers and researchers share a common language about the forecasts, their uncertainty and application. However, it is unrealistic to expect all stakeholders to become versed in hydroclimatology or forecast producers and researchers to become versed in the details confronting every stakeholder group or even every sector. Rather, all communities would benefit from an intermediary group -- personnel versed in the language of researchers, forecasters and users, in order to facilitate the transfer of information between groups.

CLIMAS or other interagency coordination efforts (e.g., the Climate, Ecosystem and Fire Applications group for fire managers) may help to fill this role.

2.6.3 Priorities for Stakeholder Driven Hydroclimatic Research

The clearest connection between stakeholders and hydroclimatic research is through forecasts. Stakeholders confront uncertainty about forecasts every time they make a decision, whether those forecasts are simply their own feelings about what might happen or sophisticated products from a government agency.

A commitment to iterative stakeholder interaction requires providing stakeholders with useable products. Stakeholder driven research programs should include sufficient resources to develop products; demonstrating a technology or developing a prototype is not sufficient. For researchers, this requires participation in product development efforts after original research activities have been completed. For the research program, this requires the flexibility and funds for hiring computer and design specialists for the development of operational tools that are accessible through the Internet.

There are many areas where different stakeholders would appreciate and potentially benefit from hydroclimatic research. However, based on stakeholder comments, in addition to the continued focus on forecast evaluation the most immediately important area of focus is the down-scaling of regional and seasonal forecasts to local event forecasts. In addition, there is potential for continued development of strong research and stakeholder relationships by focusing on the integration of precipitation data collected by stakeholders. The enthusiasm for this should not be underestimated. Some ranchers said they were willing to purchase weather stations costing $600-800, if they could be used to provide automated feeds to a central database for high-resolution areal interpolation of conditions in near real-time.

Finally, there is a need for continued documentation and formal analyses of stakeholder interaction processes and methodologies. Extant research, especially concerning structured discussions, is limited and contrasts with the rich experiences encountered in interactions described herein. While several insights were presented in this chapter, further work should based on collaboration with social scientists.

CHAPTER THREE

A REVIEW OF THE WEATHER, CLIMATE AND HYDROLOGIC FORECASTING SITUATION IN THE U.S. SOUTHWEST

3.1 INTRODUCTION

Whether explicitly recognized or not, most decisions related to natural resource management rely on of some sort of weather, climate, or hydrologic forecast. The forecasts may be produced by teams of experts using many kinds of data, sophisticated mathematical representations of physical processes, and complex objective techniques for combining results. Alternatively, an individual may rely on simple, subjective, ad hoc forecasting processes; they may simply have a feeling, based on an implicit assumption that future conditions will be much like the past. In between these extremes exists a continuum of forecast methods, including simple statistical techniques based on limited data and complex subjective heuristics.

The ubiquitous role of hydrometeorologic forecasts made them an important component of the CLIMAS project, an integrated assessment of climate vulnerability. Good forecasts enable decision makers to effectively plan proactive responses to potential climate events (Changnon and Vonnhame, 1986; Changnon et al., 1999), but use of poor forecasts can produce dire consequences (Glantz, 1982). Interactions with different groups in the Southwest (e.g., Benequista and James, 1998; Conley et al., 1999; Pagano et al., 2002) repeatedly demonstrated that many users didn't clearly understand what kinds of forecasts were available, how they were intended to be interpreted, or how well past predictions had matched reality. Further, as highly interdisciplinary efforts, integrated assessments require a shared foundation of understanding across many social and physical science disciplines (Liverman and Merideth, 2002). Not unexpectedly, many researchers joined CLIMAS having only limited knowledge of hydrometeorologic forecasts. However, our discussions with members of the hydrometeorologic community consistently revealed discrepancies in their understanding of forecast availability, procedures, interpretation, and performance.

This chapter surveys the weather, climate, and hydrologic forecasting situation existing in the U.S. Southwest, with three main objectives. The first is simply to document the diversity of forecasting entities, available products, and avenues of access that existed during a specific period, which can serve as a baseline for evaluating subsequent advances in the production and delivery of forecasts. The second objective is to provide an efficient introduction, suitable for a broad interdisciplinary audience, to forecasts and issues about their production, communication, and evaluation. Finally, the third is to identify directions for rapidly advancing the state of hydrometeorologic forecasting in ways relevant to scientific researchers, operational forecasters, potential users, and integrated assessments.

3.2 METHODS

The survey synthesized material from three types of sources: historic and current forecasts, forecasting personnel, and the scientific literature. Descriptions of forecast characteristics were developed using qualitative analyses of multiple lines of evidence.

Informational inconsistencies were resolved, where possible, by relying on information accompanying the most recent forecasts or by interviewing personnel involved with the specific issue. Material was collected from April 1998 through March 2000.

Actual forecasts and their ancillary information served as primary source material. Although some forecasts were archived in printed form, many were transient and available primarily, if not exclusively, on the World Wide Web (Web). Source material was identified through recommendations of agency personnel and forecast users and use of multiple Web search engines. While this study attempted comprehensive coverage of hydrometeorologic forecasts relevant to the Southwest, particular emphasis was given to products issued by the NWS due to their role as the official federal forecasting agency. Hartmann et al. (1999) documented details about the forecasts, including then-current Web addresses, although ephemeral materials are not retrievable. In addition, example forecast products are archived and available upon request.

This study also relied on extensive interaction with key personnel from agencies involved in producing or issuing forecasts, providing data for making forecasts, or serving as a link for communicating forecasts. Individuals were selected based on our understanding of the forecasting milieu and recommendations by others, including the solicited personnel. Significant material was obtained through a workshop (Forecast Assessment Workshop, ISPE, UA, Tucson, AZ, 8-9 July 1998) that involved the NWS Weather Forecast Offices (WFOs) of Phoenix and Tucson, NWS CBRFC, NWS Office of Hydrology, NRCS, Bureau of Reclamation, Salt River Project (SRP), Western Regional Climate Center (WRCC), and NOAA's OGP, as well as academic institutions.

The workshop relied on focused discussions to address predetermined topics (Whyte, 1977; Rubin and Rubin, 1995). In addition, experts were invited to describe various aspects of forecasting in a special session and panel discussion at the 1999 Spring Meeting of the AGU (Changnon, 1999; Davis and Pangburn, 1999; Donahue, 1999; Fread, 1999; Lawford, 1999; Lee, 1999; Sorooshian and Imam, 1999). Extended discussions were also conducted with key personnel from the CPC. Subsequent discussion and correspondence were targeted at filling information gaps about forecast procedures, interpretation, and other issues. To protect confidentiality (Dunn and Chadwick, 1999), comments are not attributed to specific participants; however, discussion notes are archived.

This survey is conceptually organized into three broad categories: weather, climate, and hydrologic forecasts. The temporal boundary between weather and climate is indistinct and was sometimes a point of disagreement within the forecast and research communities. This survey uses the CPC (1995) definition, which considered weather forecasts to cover periods shorter than one month and climate forecasts to cover periods one month and longer. Hydrologic forecasts cover both time scales due to the integrative character of hydrologic processes (e.g., snowmelt peak streamflow forecasts refer to short-term conditions, but reflect the hydrologic response to melt of seasonal snowpack accumulation). Quantitative precipitation forecasts (QPFs) are included herein as hydrologic forecasts, because they were produced specifically as inputs for flood forecasts and were typically considered hydrologic forecasts during discussions with agency personnel.

3.3 WEATHER FORECASTS

3.3.1 Forecast Products and Providers

Weather forecasts examined during this survey encompassed a tremendous variety of types covering multiple spatial and temporal scales and were available from myriad sources (Table 3.1). They typically tracked the movement and evolution of specific air masses in order to predict meteorologic quantities (e.g., daily maximum and minimum air temperatures) or the occurrence of events (e.g., precipitation, tornadoes).

The NWS had two official delivery mechanisms for their forecasts during the survey period: the NOAA Weather Radio and Weather Wire Service. However, they supported others, including the NOAA Family of Services, Weather by Telephone, the Emergency Managers Weather Information Network (EMWIN), and the Web. NWS units maintained their own Web sites; the look and feel of each site were vastly different, with varying ease of product access.

The NWS reorganization, completed in 1999 (O'Hara, 1999), generally shifted responsibilities for producing and issuing official weather forecasts to a greater number of local WFOs; 11 WFOs provided coverage for the Southwest, including the Colorado River basin. Routine general products from the WFOs consisted of brief text and tabular products presenting, at minimum, predictions of high and low temperatures, likelihood of precipitation, and wind direction and speed. They were usually issued twice daily, but updated more frequently when rapidly changing conditions warranted. Zone forecasts typically covered portions of counties (e.g., 40 zones in Arizona), while state forecasts covered larger regions (e.g., six regions in Arizona). Area forecast discussions were

Table 3.1. Weather forecasts available with southwest U.S. coverage, April 1998 - March 2000.

Forecast Producers and Providers	Forecast Products
Government Agencies	***NWS Products***
National Weather Service (NWS)	*Routine general products (1-3 day coverage)*[3]
Weather Forecast Offices	Local forecasts
Storm Prediction Center	Zone forecasts
National Hurricane Center	State forecasts
Climate Prediction Center	Area forecast discussions
Hydrometeorological Prediction Center	*Special purpose products (min.-hrs. coverage)*
Aviation Weather Center	Short-term forecasts
Air Resources Laboratory/NOAA[1]	Watches and warnings
Forecast Systems Laboratory/NOAA[1]	Severe thunderstorms
National Severe Storms Laboratory/NOAA[1]	Winter storms
Global Hydrology and Climate Center/NASA[2]	Tornadoes
Naval Research Laboratory	Aviation
Air Force Weather Agency	Marine
Western Regional Climate Center (WRCC)[4]	Weather advisories (e.g., wind, heat, fog)
Bureau of Reclamation	Special weather statements
Natural Resources Conservation Service	Significant weather outlooks
Universities	Urgent weather messages
Colorado State University	*Miscellaneous (highly variable coverage)*
Pennsylvania State University	Aviation terminal forecasts
University of Arizona	Domestic aviation en route forecasts
University of Utah	Marine forecasts
University of Washington	Fire weather forecasts
	Selected cities/traveler's forecasts
	Threats assessment
	Drought monitor
	Southeast Arizona convective outlook
	Extended forecasts (3-5 days, 6-10, 8-14 days)

1 National Oceanic and Atmospheric Administration.
2 National Aeronautical and Space Administration.
3 Maximum and minimum temperatures and precipitation, sometimes winds, relative humidity.
4 WRCC includes state and academic partners. SRP has public and private components.
5 Inclusion does not imply endorsement of vendor services or products.

Table 3.1, continued. Weather forecasts available with southwest U.S. coverage, April 1998 - March 2000.

Forecast Producers and Providers	Forecast Products
Commercial Entities[5]	***Commercial Products***
Media outlets	City forecasts (1.5-, 5-, 10-, 14-days)[3]
USA Today	Threat alerts (e.g., wind, heat, fog, storms)
Local newspapers	Agriculture forecasts
Radio stations	Frost alerts and warnings
Local television stations	Fruit harvest forecasts
The Weather Channel	Soil moisture forecasts
Cable News Network (CNN)	Cloud cover forecasts
AccuWeather	Marine forecasts
Baja Weather Service	Recreation, port, shipping route forecasts
Compu-Weather	Aviation forecasts
Fox Weather	Film industry forecasts
Kavouras, Inc.	Ski resort forecasts
Unisys	Ultraviolet radiation recreation forecasts
Weather Sites, Inc.	Utilities (e.g., power, transportation) forecasts
Salt River Project (SRP)[4]	
The Old Farmer's Almanac	
Private Non-commercial Entities	
Amateur forecasters	
Hobbyists	

[1] National Oceanic and Atmospheric Administration.
[2] National Aeronautical and Space Administration.
[3] Maximum and minimum temperatures and precipitation, sometimes winds, relative humidity.
[4] WRCC includes state and academic partners. SRP has public and private components.
[5] Inclusion does not imply endorsement of vendor services or products.

unique among routine products. They used technical terms and cryptic abbreviations, but presented the rationale WFO forecasters used in making a specific forecast, including recent performance of numerical weather models, unique conditions underlying skepticism or confidence in model results, conditions creating forecast difficulty and uncertainty, and prospects for improved or deteriorating predictability. In 1998, the Tucson, Arizona WFO began to experimentally issue Southeast Arizona Convective Outlooks each afternoon during the summer monsoon season. They differed from routine products by forecasting thunderstorm areal coverage and location, expected direction of motion, and conditional probabilities of storm severity and precipitation totals.

When faced with prospective extreme weather conditions, WFOs could issue a variety of special purpose forecasts for locations (e.g., canyon areas known for hazardous driving during high winds) within their county warning areas. However, the NWS Storm Prediction Center had the responsibility for issuing official watches and warnings for severe thunderstorms and tornadoes, including the "watch boxes" seen on television. Affected WFOs also issued Storm Prediction Center watches and warnings through their usual mechanisms, creating the need for intensive communication and coordination among national, regional, and local NWS units. Similar relationships existed between WFOs and the NWS National Hurricane Center regarding infrequent tropical storms and hurricanes affecting the Southwest.

The CPC was responsible for the NWS threats assessment, which transitioned from "experimental" to "operational" status during the study period. The forecasts consisted of weekly graphical products, sometimes supplemented with daily text updates, describing the potential for extreme hydrometeorologic conditions (e.g., extreme heat, heavy rains) based on NWS medium- (3-5 day), extended- (6-10 day), and long- (monthly and seasonal) range forecasts, as well as hydrologic forecasts.

Forecasts from non-WFO NWS, NOAA, Department of Defense, and National Aeronautical and Space Administration units and several universities were routinely accessible to the public, although they were generated to provide guidance to the WFOs in creating local forecasts or to support internal operations, including research activities. These products were highly varied in content, complexity, and clarity of communication, but typically simply provided output from individual numerical weather models.

Commercial forecasts consisted of two types: free and fee- or subscription-based. Free forecasts were often associated with providers deriving revenue from advertising (e.g., The Weather Channel) or were offered as an inducement to cost-based forecasts (e.g., Baja Weather Service). Costs were typically associated with unique types of forecasts for user-specified locations. Some custom forecasts ultimately appeared in newspapers and on television and radio; AccuWeather produced many such products, including the "crawl lines" placed on the top or bottom of television screens that communicated NWS issuance of official weather watches and warnings. Some vendors targeted specific markets by offering "one stop shopping" for easy access to forecasts, along with other market-sector information (e.g., Weather Sites, Fox Weather). Often, free forecasts were simply copies of official NWS forecasts or products available from other providers, although they sometimes included only portions of the original forecast and ignored essential ancillary products (e.g., text discussions, forecast category definitions). Unisys transformed NWS weather model results into attractive graphical products, citing the NWS as the data source; however, it was not clear that the product represented intermediary NWS information, not an official forecast. SRP produced temperature and relative humidity forecasts primarily for internal power generation and marketing operations, but through cooperative agreements, provided some products to outside clients, including government agencies (e.g., advisories for lightning, high winds, and heavy rains for the Phoenix, Arizona area). The Old Farmer's Almanac, an annual magazine, was unique in providing weather forecasts (e.g., "stormy", "sunny") with lead times more than a year in advance.

Some governmental entities (e.g., WRCC, NRCS) operated much like commercial vendors, using the Web to provide "one stop shopping" by linking to or reformatting NWS products and offering unique free or subscription-based products. As such, their products had similar caveats; in addition, continuity of agency efforts was poor, with many outdated products. Unique products included the Bureau of Reclamation's daily forecasts of daily precipitation depth and Penman evaporation offered via their Web-based Agricultural Water Resources Decision Support (AWARDS) System.

3.3.2 Forecast Techniques

Weather forecasts encountered in this study were typically generated using complex, non-linear, dynamic numerical models describing physical interactions between solar radiation and atmosphere, ocean, and land systems. In making an official forecast, WFO meteorologists subjectively combined results from many models (Table 3.2), some

Table 3.2. Numerical models used to produce National Weather Service weather forecasts, April 1998 - March 2000[1].

Model Name and Acronym	Reference
Nested Grid Model (NGM)	Hoke et al. (1989)
Eta Models (Eta, meso-Eta, Eta-10)	Janzic (1994), Rogers et al. (1995), Staudenmaier (1996a-d, 1997a-c), Mittlestadt (1997)
Aviation (AVN) Model	Kalnay et al. (1990)
Medium Range Forecast (MRF) Model	National Meteorological Center (1988), Kalnay et al. (1990)
Mesoscale Analysis and Predictions System/ Rapid Update Cycle (MAPS/RUC) Model	Bleck and Benjamin (1993), Benjamin et al. (1998)
Navy Operational Global Atmospheric Prediction Systems (NOGAPS)	Rosmond (1992), Hogan and Brody (1993), Air Weather Service (1996), Staudenmaier (1997d)
Mesoscale Model - Fifth Generation (MM5)	Anthes and Warner (1978), Dudhia et al. (1999)
Regional Atmospheric Modeling System (RAMS)	Pielke (1985), Pielke et al. (1992), Cotton et al. (1994, 1995)
Global Environmental Multiscale (GEM) Model	Côté et al. (1998)
United Kingdom Meteorological (UKMET) Model	Cullen (1993)
European Centre for Medium Range Weather Forecasts (ECMWF) Model	Woods (1997)

[1] Not all models used in a single forecast; selection of models and outputs determined by forecasters.

generated by non-NWS entities, with recent local observations and accumulated personal expertise. The models differed in their spatial and temporal resolutions, internal structures, process descriptions, and parameterizations. Using variations of recent observations and model characteristics, repeated model runs were used to generate multiple outputs, comprising an ensemble of forecasts. Models were often interdependent, as some provided boundary conditions for others, had multiple implementations, or were also subjectively combined prior to WFO access. Details of the specific variables used, variations in starting conditions, number of model runs, and model run lengths were highly variable and often difficult to explicitly determine from available documentation.

Many non-WFO forecast producers presented results from individual numerical models as stand-alone weather forecasts, although WFO forecasters considered them only as "sensible weather guidance". An exception was SRP, which operated like a WFO. In general, private sector forecast providers had proprietary interest in their techniques and typically withheld descriptions of their specific methods.

The numerical weather models listed in Table 3.2 changed frequently (sometimes almost monthly) throughout the study period. Some model adjustments were systemic, providing greater model resolution, larger areal coverage, longer model runs, shifted model run schedules, or diversification of model outputs. Others corrected process parameters to improve model performance for a specific region or type of condition. Notifications of model modifications were distributed as public information statements using NWS' standard delivery mechanisms, but the comprehensiveness of readily available archived documentation was erratic.

3.4 CLIMATE FORECASTS

3.4.1 Forecast Products and Providers

Compared to weather forecasts, there were fewer climate forecasts available and fewer providers during this survey (Table 3.3). Climate forecasts made statements about average or cumulative conditions, rather than specific events, anticipated to occur over an extended period of time.

The CPC produced the official U.S. governmental climate forecasts. Although originally distributed as bulletins (e.g., CPC, 1997), during the survey period the climate forecasts were issued only via the Web. The product consisted of a suite of forecasts, issued monthly; they included one 1-month outlook and a series of 13 3-month outlooks each offset by one month. For any single outlook, the CPC provided: (1) maps of surface air temperature and precipitation probability anomalies, (2) a legend describing appropriate interpretation of the probability anomaly maps, (3) a text discussion, (4) maps and tables of historic climatology and probability class limits, and (5) skill maps for some forecast techniques. The climate outlook maps showed likelihoods of occurrence, expressed as probability anomalies, for average air temperature or total precipitation over the period to fall within tercile categories defined by the upper, middle, or lower third of conditions reflected in the historic record from 1961-1990. The maps almost exclusively indicated increased expectations for conditions to fall in the outer categories. The legend

Table 3.3. Providers and characteristics of climate forecasts available with southwest U.S. coverage, April 1998 - March 2000.

Forecast Producers and Providers	Forecast Product Characteristics
Government Agencies	***Products***
Climate Prediction Center/NWS[1]	Monthly climate outlooks
NWS Weather Forecast Offices	3-month seasonal climate outlooks
Goddard Institute for Space Studies/NASA[2]	Customized conversions of climate outlooks
Government-Academic Partnerships	***Lead times***
Western Regional Climate Center (WRCC)	0.5-months
International Research Institute for Climate Prediction	0.5- to 13-months
Experimental Climate Prediction Center	0.5- to 18-months
Commercial Entities[3]	***Variables***
Salt River Project (SRP)[4]	Average temperature
AccuWeather	Total precipitation
Fox Weather	Heating and cooling degree days
Advanced Forecasting Corporation	Custom variables (e.g., number of rainy days)
Environmental Dynamics Research, Inc.	
Old Farmer's Almanac	

[1] National Weather Service
[2] National Aeronautical and Space Administration
[3] Inclusion does not imply endorsement of vendor services or products.
[4] SRP has public and private components.

indicated that forecasters had an option to increase the expectation for conditions to fall within the central tercile. For that case, the legend decreased expectations for the outer categories (maximum 5% each), but due to a typographical error did not increase expectations for the central category. When forecasters specified an anomalous probability for a region, there was an implicit statement that the techniques used to create that outlook had some record of skill for that region for that forecast period. In contrast, a "climatology" designation could mean several forecast techniques disagreed about possible conditions over the forecast period or that no forecast techniques had shown skill for that region and season.

It was common for other organizations, including the media and governmental agencies, to link to or collect and reformat the CPC climate outlooks. However, some organizations provided only portions of the entire CPC product (e.g., outlook maps, without text discussions or even a legend). Some WFOs and the WRCC converted CPC climate outlooks into specialized products (e.g., expected number of rainy days). Groups that had established close relationships with some WFOs got special climate forecasts without cost, while the WRCC provided their products on a subscription basis.

The IRI produced climate forecasts similar, but not directly comparable, to the CPC official outlooks. IRI forecasts covered only non-overlapping 3-month seasons, but extended into Mexico rather than stopping at the U.S. border. IRI forecast maps specified precise probabilities (e.g., 27% rather than probability anomaly ranges) of conditions falling within tercile categories, and the legend was integrated into each map. IRI maps of tercile boundaries indicated they were based on conditions during 1950-1995, not 1961-1990. IRI specified that the "climatology" designation meant forecasters had no basis for departing from historically based probability distributions. IRI maps also masked out, and provided no forecast, for regions typically receiving less than 15% of their annual total precipitation during that season. IRI forecasts showed uniform probabilities across large regions, rather than contours centered on subregions with the highest anomalies. Additional maps for the first 3-month season showed probabilities for conditions to fall within the top or bottom 15^{th} percentile of historic records. Finally, only registered users could obtain the Web-based forecast products, although several months after the forecast season had passed, the products became accessible by all. While a disclaimer stated that IRI forecasts were intended only for research purposes, they had been used in applications (OGP, 1999) and products were sometimes labeled "official".

CPC also produced experimental probability of exceedance forecasts that contained much more information than their official outlooks. The experimental products consisted of a series of 102 graphs, with each series corresponding to a probability anomaly map of the official outlook and each graph representing a subregion within the U.S. (Barnston et al., 2000). The graphs expressed the climate forecasts using continuous distributions of the probability that temperatures or precipitation quantities would be exceeeded. They also showed historic observations, the associated climatologic distribution, recent observations, an envelope of uncertainty about the forecast distribution, and text commentary that highlighted forecast attributes.

Both the Experimental Climate Prediction Center and the Goddard Institute for Space Studies generated forecasts, not for decision making, but in order to test dynamic numerical models they were developing or extending. However, the forecasts were publicly accessible on the organizations' Web sites and sometimes labeled "official" by the Experimental Climate Prediction Center. The organizations' forecasts encompassed many more variables (e.g., wind speed, relative humidity, soil moisture) than official NWS products and were expressed as quantities, not probabilities.

SRP generated climate forecasts primarily for internal use to support planning for their water resources and power operations. Other commercial producers of climate forecasts were clearly targeting external commercial interests, including the financial and insurance industries. Some vendors provided products similar to official CPC outlooks (e.g., AccuWeather, Fox Weather). Others offered forecasts with longer lead times (e.g., 18 months from Advanced Forecasting) or specialty variables (e.g., degree-day outlooks from Environmental Research Dynamics). Many commercial products, standard or customized, were expressed as quantities, not probabilities.

3.4.2 Forecast Techniques

Compared to weather forecasts, the climate forecasts encountered in this study were produced from a wider variety of techniques (Table 3.4) that included both statistical and conceptual modeling approaches. CPC and IRI forecasts were created by subjectively combining results from several techniques and sometimes making

Table 3.4. Techniques used to produce climate forecasts, April 1998 - March 2000.

Technique Name and Acronym	References
Climate Prediction Center (CPC)	
Canonical Correlation Analysis (CCA)	Barnston (1994), Barnston and Smith (1996)
Screen Multiple Linear Regression (SMLR)	Unger (1996a,b)
Optimal Climate Normals (OCN)	Huang et al. (1996a)
Soil Moisture Tool	CPC (1995), Huang et al. (1996b)
Constructed Analogs (CA)	CPC (1995)
Composite Analysis (CA)	Higgins and Mo (1997), CPC (2000)
Coupled Model Prediction (CMP)	Ji et al. (1994a,b), Barnston (1998), Livezey et al. (1996)
International Research Institute	
Climate Community Model (CCM3)	Kiehl et al. (1996, 1998)
European Community Hamburg (ECHAM) Model	Barnett et al. (1994), Bengtsson et al. (1993)
Medium Range Forecast (MRF) Model	National Meteorological Center (1988), Kalnay et al. (1990)
Statistical Analyses	Goddard et al. (2000)
Experimental Climate Prediction Center	
Global Spectral Model (GSM)	Roads et al. (1999), Kalnay et al. (1996)
Regional Spectral Model (RSM)	Chen et al. (1999), Juang et al. (1997)
Mesoscale Spectral Model (MSM)	Juang (2000)
Oberhuber Global Isopycnic Ocean Model	Oberhuber (1993)
Hybrid Climate Model (HCM)	Pierce (1996)
Goddard Institute for Space Studies	
SI97	Wilder et al. (1997), Borenstein et al. (1998)
Salt River Project	
Entropy Model	Salt River Project (SRP, 1998)
Old Farmer's Almanac	
Astronomical model	Yankee Publishing (2000)

adjustments based on current observations, recent research, and expert judgement. Others (e.g., Experimental Climate Prediction Center, Goddard Institute for Space Studies) were based on unadjusted output from their numerical models. Techniques for producing commercial products were proprietary and not described for the general public.

CPC's roster of statistically based forecast techniques was typical of those used by other groups. A form of multivariate linear regression, canonical correlation analysis attempted to represent slowly evolving effects of ocean conditions on the atmosphere, such as the El Niño-Southern Oscillation (ENSO) and the North Atlantic Oscillation. The technique predicted spatial patterns of temperature and precipitation anomalies based on spatial anomalies of global sea surface temperatures (SSTs), atmospheric pressure heights, and continental-scale temperature and precipitation. Screen multiple linear regression was similar to canonical correlation analysis, but provided only localized forecasts; it was used where significant geographic features (e.g., mountains, coastlines) caused climate to be largely controlled by only a few ocean or atmospheric conditions. The optimal climate normal technique subtracted climatologic averages (e.g., 1961-1990) from averages of the past 10 years for temperature and 15 years for precipitation, although other periods could be more optimal for some regions. The technique accounted for interannual persistence of conditions within interdecadal climate regimes or long-term trends, but was apt to fail during periods of regime transition. The soil-moisture tool used prior soil-moisture conditions and temperature anomalies to account for intraseasonal effects of soil moisture on regional surface climatology. Composite analysis and constructed analogs relied on similar conditions from the historic record (e.g., years with the same ENSO state) to suggest potential future conditions.

The CPC typically made less use of outputs from global climate models (GCMs) than other climate forecast providers. The GCMs attempted to consider the myriad physical processes that affect climate, including the mutual influence between the oceans and atmosphere. However, some GCMs contained more detail about slowly evolving ocean-atmosphere interactions (e.g., heat transfer), while others had more detail about rapidly changing atmospheric conditions (e.g., deep cumulus convection). Typically, one or several GCMs that coupled ocean and atmospheric behavior were used with recent observations and slight variations thereof, to forecast several possible SSTs. The forecasted SSTs and their slight variations were then used as multiple starting conditions for GCMs that focused more exclusively on atmospheric processes. Each model run comprised one member in an ensemble of forecasts produced by a GCM. Details of the specific variables used, variations in starting conditions, number of model runs, and model run lengths were highly variable and often difficult to explicitly determine from available documentation.

3.5 HYDROLOGIC FORECASTS

3.5.1 Forecast Products and Providers

Relatively few entities were involved in producing hydrologic forecasts (Table 3.5), although collectively the products covered time scales spanning the equivalent of

Table 3.5. Hydrologic forecasts available with southwest U.S. coverage, April 1998 - March 2000.

Forecast Producers and Providers	Forecast Products
Government Agencies	***Short-range Products (lead times less than one month)[1]***
National Weather Service (NWS)	Flash flood watches and warnings
River Forecast Centers	Flood watches and warnings
Weather Forecast Offices	Flood statements
Hydrometeorological Prediction Center	Areal flash flood guidance (zone, county, urban area, headwater)
Climate Prediction Center	Threshold runoff guidance
National Environmental Satellite Data And Information Services/NOAA[2]	Quantitative precipitation forecasts
Natural Resources Conservation Service	Stage crest (peak water level) forecasts
Central Arizona Project	Daily stage forecasts (river, lake, reservoir)
California Department of Water Resources	Daily discharge forecasts
Bureau of Reclamation	River gauge reviews
Commercial Entities[3]	River recreational statements
Salt River Project[4]	River statements
	Runoff recession forecasts
	Low flow forecasts
	Threats assessment
	Long-range Products (lead times one month and longer)
	Flood potential outlooks
	Snowmelt peak flows
	Water supply outlooks (seasonal streamflow volume forecasts)
	Flood control forecasts
	Reservoir monthly inflow forecasts
	End of month reservoir contents

[1] Refers to beginning of forecast; portions may extend beyond one month.
[2] National Oceanic and Atmospheric Administration.
[3] Inclusion does not imply endorsement of vendor services or products.
[4] Salt River Project has public and private components.

both weather and climate forecasts. As with weather and climate forecasts, the NWS provided the official government hydrologic forecasts. WFOs were responsible for issuing flood and flash food watches and warnings for their service areas, but relied on coordinated consultation with NWS River Forecast Centers (RFCs) and local emergency management agencies (e.g., flood control districts); four RFCs provided coverage for watersheds in the Southwest. Depending on the specific product, flood forecasts had lead times ranging from minutes to several hours and areal coverage ranging from single stream locations to multiple counties. They generally provided qualitative statements about the potential for extreme conditions, without quantifying streamflows, water levels, or probabilities of occurrence. Flood statements were used to terminate watches or warnings. Quantitative guidance products (e.g., headwater flash flood guidance, threshold runoff) were generated by the RFCs and WFOs, primarily for internal use. However, at least some WFOs also shared the products with local emergency management agencies. Also generated and issued by WFOs, flood potential outlooks provided text-based descriptions of the potential for water levels to cause damage to property, but over the next several weeks.

QPFs were created by the NWS Hydrometeorological Prediction Center (HPC) and local WFOs, primarily as guidance for use in generating other products. HPC QPFs were publicly available on their Web site, but were not official products intended for public use. They consisted of national maps showing anticipated depths of rainfall in six- or 24-hour increments over the next one or two days, snow depths, or up to four kinds of excessive rainfall potential, all without probabilities.

A variety of daily stage (water level) or discharge forecasts were made by the RFCs and then issued, without modification, by the WFOs. Although given a variety of names, the products often contained similar kinds of information, ranging from qualitative descriptions of current or anticipated conditions, to reviews of recent and historic conditions, to quantitative stage or discharge predictions without accompanying probabilities. They were typically issued with one- to five-day lead times, although there was variation in temporal coverage depending on location. The CBRFC also had experimental probabilistic discharge forecasts for some Colorado watersheds available for public access on their Web site, although in forms (e.g., long tables of model output values) that would discourage untrained users.

Historically, snowmelt peak flow forecasts and water supply outlooks were issued by the RFCs in monthly bulletins (e.g., CBRFC, 1992, 1998). However, during the survey period, the products were increasingly available through RFC Web sites and WFO delivery mechanisms. In the Southwest, peak flow forecasts were issued for March-June and March-April for the upper and lower Colorado River basins, respectively. They predicted maximum mean daily flows expected to occur, from melt of the past winter's accumulated snow pack, sometime during the snowmelt season (March-May for Arizona, April-July for most other locations). The forecasts were expressed as flow rates with five levels of probability (90, 75, 50, 25, and 10% exceedance quantiles). They were also accompanied by historic maximum peak flows, average peak flows, flood flows (at which damages would begin), and the normal timing of peak flow occurrence.

Water supply outlooks were unique in that they reflected the absence of water management influences (termed "naturalized" flows); other hydrologic forecasts considered at least some aspects of current water diversions or reservoir regulations. Water supply outlooks were issued biweekly, January-June and January-April for the upper and lower Colorado River basins, respectively, but sometimes earlier with early snow accumulation. They had varying temporal coverage reflecting basin seasonal flow characteristics (e.g., January-May for the Gila River, April-July for the San Juan River), and got shorter as the forecast season progressed. Water supplies were expressed as "reasonable minimum", "most probable", and "reasonable maximum" seasonal total water volumes, respectively corresponding to 90, 50, and 10% exceedance probabilities. They were compared to 1961-1990 median volumes and disaggregated into monthly forecast volumes as well. CBRFC graphical products showed forecast flow volumes relative to climatological median volumes, with no probabilities, while other RFCs used alternative formats. The CBRFC also generated alternative experimental water supply outlooks, based on newer methods, but only for internal evaluation.

Concurrently issued forecasts of flood control, reservoir monthly inflows, and end-of-month reservoir contents were all variants of the water supply forecasts. Generally, they included more water management influences and were expressed only as quantities (e.g., percent of 1961-1990 median flows, percent reservoir capacity), without probabilities. The CBRFC also produced extended exceedance probability water supply outlooks, covering up to two years, for the Bureau of Reclamation's use in regulating reservoirs along the Colorado River and its tributaries.

The NRCS also issued water supply outlooks for the Southwest, in coordination with the CBRFC and SRP. Their official forecast values were identical to CBRFC values, but included 70% and 30% exceedance quantiles as well. NRCS also produced lake and reservoir stage forecasts, peak flow forecasts, runoff recession, and low flow forecasts, with varied temporal coverage and lead times, for specific clients under special arrangements. NRCS products were issued via bulletins (e.g., Soil Conservation Service and NWS, 1994), their Web site, the NRCS Centralized Forecast System, and direct communication with clients.

SRP, the Central Arizona Project, and the California Department of Water Resources produced water supply outlooks for managing their own water projects. SRP also produced QPFs for late summer tropical storms and during winter, as well as forecasts of snow accumulation elevations throughout the winter. SRP QPF forecasts covered six- to 24-hour periods with lead times extending to ten days. SRP products were available only for internal operations, with the exception of the water supply outlooks for the Salt and Verde rivers, which were provided to the CBRFC and NRCS for producing official coordinated forecasts.

During this survey, the NOAA National Environmental Satellite Data and Information Service had a publicly accessible experimental flash flood Web site. It provided recent satellite-based estimates of rain rates, atmospheric precipitable water, and soil wetness on which to base forecasts of flash flood potential. It also provided tutorials on making flood forecasts, targeted at potential users (e.g., canoe livery owners).

Finally, even though many universities and research groups were involved in developing new hydrologic models and forecasting tools during the survey period, none were found that provided operational forecast products. In fact, few groups other than those mentioned referred to hydrologic forecasts at all. One exception was the Bureau of Reclamation, which provided QPFs, obtained from NWS sources, through their subscription-based AWARDS system and freely accessible Rivers and Meteorology Group Web site. However, they did not provide other hydrologic forecasts.

3.5.2 Forecast Techniques

Hydrologic forecasts were made using a variety of techniques (Table 3.6). Short-range hydrologic forecasts involved intensive coordination between WFOs, RFCs, and even local emergency management agencies. Like weather forecasts, QPFs were generated by subjectively combining outputs from multiple numerical weather models. QPFs from WFOs were generally relied upon the most, by both WFOs and RFCs. Flash flood forecasts often were based on real-time monitoring of watershed conditions, while flood forecasts were also based on unit hydrographs driven by real-time precipitation observations, tempered by expert judgement and guidance products. Guidance products were based on continuous accounting of soil moisture and snow cover, generally using the same procedures as for daily stage and discharge products. They were generated using the NWS River Forecast System (NWSRFS), a complex software system comprised of over 400,000 lines of code. At the heart of this system were models for snow accumulation and ablation, rainfall-runoff relationships, and routing of flows down river

Table 3.6. Techniques used to produce hydrologic forecasts, April 1998 - March 2000.

Technique Name and Acronym	References
Numerical weather models[1]	See Table 2
Balling precipitation model[1]	Salt River Project (SRP, 1998)
Observing systems	
Unit hydrographs	Maidment (1993)
Curve number method	Soil Conservation Service (1985, 1986)
National Weather Service River Forecast System (NWSRFS)	Office of Hydrology (1996), Hydrologic Research Laboratory (1998)
Snow accumulation and ablation model (SNOW-17)	Anderson (1973)
Antecedent Precipitation Index (API) models	Kohler and Linsley (1951), Nemec and Sittner (1982)
Sacramento Soil Moisture Accounting (SAC-SMA) model	Burnash et al. (1973), Burnash (1995)
Lag and k flow routing models	Linsley et al. (1975)
Ensemble streamflow prediction (ESP)	Day (1985)
Multivariate linear regression	Colorado Basin River Forecast Center (CBRFC, 1992), Garen (1992)

[1]For quantitative precipitation forecasts.

channels. All of the models were developed more than 30 years ago, although upgrades have occurred more recently. The most common approach was to use the NWSRFS deterministically, using a single series of inputs (e.g., from a QPF) to produce a single forecast. Experimental probabilistic forecasts generated by some RFCs (including experimental water supply outlooks) forced the system with multiple inputs selected from historic meteorologic records, termed ensemble streamflow prediction (ESP). The California Department of Water Resources also used ESP for their forecasts, with the Sacramento Soil Moisture Accounting (SAC-SMA) model as the kernel.

Both the CBRFC and NRCS based their long-range forecasts on multivariate regression relationships rather than dynamic models. Unique regressions for each forecast period and location used subsets of monthly or seasonal observations of precipitation, streamflow, ground-based snow-water depths, and routed forecasted streamflows. The regression equations produced only a single deterministic water supply volume representing the 50% exceedance forecast. Forecast volumes for additional exceedance quantiles were obtained by overlaying a normalized error distribution, determined during equation fitting, centered on the deterministic regression forecast. Regression equations for some Arizona locations incorporated ENSO index values, allowing their water supply outlooks to reflect climatic teleconnections. NRCS used curve-linear equations with variables decorrelated using principal component analysis. CBRFC forecasters selected one of several linear regression equations, some of which used transformed variables. Additional statistical analyses were used to disaggregate seasonal outlooks into monthly volumes. SRP used regression models as well as techniques based on curve numbers and input from their climate model. After the CBRFC, NRCS, and SRP made their independent water supply forecasts, they relied on their expert judgement to subjectively coordinate forecasts into a final official product with identical values.

3.6 DISCUSSION

In reviewing the forecasts encountered in this survey, several issues became apparent that relate to forecast producers or potential users. Critique of individual forecast techniques is beyond the scope of this survey. The point is not to judge one model better than another or disparage forecasting efforts. Rather, this discussion is intended to initiate a dialogue about the process of developing and providing forecasts, including how forecasts can be made accessible to a variety of potential users in ways that improve the ease, accuracy, and reliability of interpretation and application. Some topics concern dilemmas that lack a clear way forward.

3.6.1 The Forecast Milieu

During this survey, potential users of hydrometeorologic forecasts faced myriad products issued by a complex mix of agencies, universities, private enterprises, and other organizations. Forecasts were issued via a complex mix of media as well, including published reports, newspaper, radio, and, increasingly, computers. The sheer variety of forecast products and sources poses the potential to limit the credibility of any single forecast. A user might well question why slightly different forecasts are distributed by different agencies or, when forecasts are quite different, wonder which is more reliable. As Pagano et al. (1999) found, users can become overwhelmed by the many choices available and then settle for the forecast easiest to access, rather than the best to use. In addition, the state of forecasting was constantly evolving. New products were generated and standard products were communicated in new ways, on an ever-changing trajectory. Easily available Internet access radically changed the means for obtaining forecast products. Many products and ancillary information (e.g., technique descriptions, input data) were delivered primarily, if not exclusively, via the Web. The most efficient approach for learning about available NWS forecasts was by contacting WFO staff, who also assisted in product interpretation. Pagano et al. (1999) found that users who had ongoing relationships with WFOs had the best understanding of forecasts related to the 1997-1998 El Niño event.

3.6.2 Official, Operational, Experimental, and Research Forecasts

In practice, there appeared to be little distinction among official, operational, experimental, and research forecasts. However, clear identification has practical importance because users now have direct access to all forecast types. Operational products are routinely produced by an agency, using established procedures that have undergone extensive review. There was some disagreement about whether official forecasts included any publicly available operational product of the NWS, the official forecasting agency, or only some subset required by NWS legal mandates or internal criteria. NWS documentation did not identify whether products were discretionary or mandatory. The NWS did, however, distinguish among official channels for providing products; NOAA Weather Radio was an official source for weather forecasts; the Internet was not. Experimental products have not yet received official sanction, although they may be generated in an operational setting for an extended period of time to test whether they warrant transition to higher status. Research products are at even earlier stages of development. However, some were posted on the Web, in forms that looked like operational forecasts, as a means of sharing results and demonstrating conversion of research into useable products.

Should only NWS forecasts be labeled official? There was clearly potential for confusion when non-NWS providers labeled some of their climate forecasts "official", but the NWS does not have exclusive rights to the term (Kerr, 1990). What responsibilities do research groups have when making their forecasts publicly accessible? Research forecasts may appear attractive to users because they provide higher resolution, longer lead times, or precise quantities rather than probabilities, but fundamentally they are more speculative than products that have advanced to operational or official status.

3.6.3 Documentation

Documentation about the forecasts encountered in this survey varied greatly in quality and availability to users. Inevitably, ancillary information on the Web more accurately reflected current interpretations and techniques than published literature, because electronic texts had been periodically updated. Discussions accompanying NWS area weather forecasts and CPC climate outlooks were unique in describing details about the production of individual forecasts. For most other products, those details were simply unavailable. The absence of documentation, describing how expert judgement was incorporated into the forecasts or what conditions were used to initialize models, limits opportunities to improve products through retrospective analyses of forecast processes.

Clear documentation about hydrologic forecasts was particularly difficult to obtain without going directly to the forecasters. It appeared that descriptions of NWS hydrologic forecasting operations focused almost exclusively on plans for the future rather than actual practices, in order to garner support for a hydrologic modernization initiative analogous to that for meteorologic operations. In some cases the documentation was inconsistent and out-dated, posing difficulty in distinguishing between modernization plans and what procedures were really used at various localities.

3.6.4 Forecast Interpretation

Every advanced forecast represents a tremendous investment: in observation systems, computational capabilities, physical process research, and professional training. However, even the best forecasts can be worthless if users misinterpret them. Text-based forecasts used terms with specific meaning for forecasters (e.g., Branick, 1996) but without intuitive interpretation by users (van Bussem, 1999). Relative magnitudes of numerical values, including probabilities, can be reliably interpreted, but confusion often exists about the meaning of forecast variables associated with the probabilities (van Bussem, 1999).

In particular, proper interpretation of probability of precipitation forecasts engendered extensive debate. Technically, the forecasts indicate the chance of precipitation occurring at any single point within a forecast area (NWS, 1995). The probability can be determined by assigning the value for a single point (e.g., the local airport) throughout the forecast area, or by averaging the probabilities for several points (e.g., rain-gauge locations) within a forecast area. WFO forecasters also described the forecast as the expected areal coverage of precipitation within the forecast area. However, the two definitions are equivalent only when averaged over many events (Schaefer and Livingston, 1990). During the peak of the summer monsoon season, areal coverage interpretations are appropriate because storms are likely to occur somewhere within the forecast area. In contrast, winter forecasts are more appropriately considered an average probability because winter storms have broad areal extent; an areal coverage interpretation would require rarely used high forecast values (e.g., 70%). NWS precipitation forecasts did not identify the intended interpretation. Further, neither interpretation is consistent with what most people think, including many meteorologists (van Bussem, 1999), who interpret it as the chance of precipitation occurring somewhere in the forecast area.

Probabilistic climate outlooks were also often misunderstood, both by researchers and users. The concentric contours and probability anomalies in CPC forecasts appeared to be more confusing than the uniform regions and explicit probability distributions of the IRI forecasts. The climatology designation was especially misleading in suggesting that forecasters attributed equal likelihood to all conditions, when they actually meant forecast uncertainty was so great that likelihoods were unknown and no forecast was possible. The climate forecasts also offered a limited perspective, with probability anomalies expressed relative only to a subset of historic records (e.g., 1961-1990 for CPC forecasts). With understanding of decadal- and centennial-scale climate regimes improving, neglecting to communicate more extensive historic information seems ill advised, especially for decisions sensitive to extreme conditions or with long-lasting consequences.

Seasonal water supply forecasts posed a range of interpretive problems. First, as "naturalized" flows, they required users to adjust projected runoff volumes for anticipated diversions and reservoir regulations. The adjustments could be complex (CBRFC, undated) and significant (e.g., 34 adjustments for the Colorado River near Cisco, Utah, that cumulatively reduced naturalized flows by 30%), yet incomplete in representing all human impacts. Further, adjustments were based on typical management decisions that would be unrealistic during extreme conditions. Second, for rivers with skewed flows, declaring the deterministic forecast value "most probable" conveyed a false sense that it had higher probability than any other value. While expected values, statistically, are the most probable, medians represent only the midpoint of a distribution; they are expected to be too high one-half the time and too low the other half. Third, calling the 10% and 90% exceedance forecasts "reasonable" maximums and minimums conveyed a false sense of their appropriateness for decision making. Reasonableness depends on decsion makers' risk tolerance and loss functions unique to each situation. Further, interpretation of the exceedance quantiles was problematic because the quantiles were based on a normal distribution of regression error, shifted so the coordinated forecast represented the mean of the error distribution. The error generally remained constant from year to year, neglecting variations in uncertainty based on forecast magnitudes. Alternatively, ESP procedures provide probabilistic forecasts that better reflect total forecast uncertainty, because they incorporate non-linear impacts of meteorologic variability as well as unavoidable model errors.

3.6.5 Forecasting Flexibility

The state of meteorologic forecasting can be characterized by rapid incorporation of research findings and products. New forecast techniques moved relatively quickly from research to experimental to operational status. Experimental products were routinely made available to forecasters, and operational forecasts were adjusted based on recent diagnoses and improved understanding of ocean and atmospheric dynamics and linkages. The meteorologic forecasting situation resulted from a distinct shift in NWS institutional philosophy (Mittelstadt, 1997). Previously, NWS forecasting models were limited to those passing development and evaluation thresholds; they were used unchanged until major scientific and technological advancements were incorporated and evaluated. Subsequently, however, model changes were incorporated as soon as they passed initial testing and operational adjustments could be made (e.g., data handling).

In addition, because meteorologic forecasters had broad flexibility in generating their products, they could combine results from many different NWS units, each of which maintained responsibility for their own models, as well as forecasts generated by non-

NWS groups. Forecasters had flexibility to give varying precedence to different forecast techniques in different regions, during different seasons, and for unusual conditions.

In contrast, the state of hydrologic forecasting can be characterized by relatively slow evolution, with constraints imposed by complex legacy data management systems, longstanding standard operating procedures, and an institutional preference for uniformity in operations. (Legacy systems neglect modern computer capabilities in order to maintain consistency with procedures developed with now-abandoned computer architectures.) During the survey period, the NWS had a strong commitment to only two conceptual hydrologic models (the Antecedent Precipitation Index and SAC-SMA). Forecast improvement efforts focused primarily on improved data access and displays, approaches for implementing ESP, and statistical analyses of model outputs, rather than upgrading conceptual models. The institutional philosophy was that new models were required to fit within the existing data management infrastructure and demonstrate improved performance in an independent operational setting over several years. Those requirements frustrated members of the hydrologic research community who had developed new models or diagnoses that they thought should be incorporated into operational forecasts, but who hadn't developed operational systems parallel to those of NWS.

NWS hydrologic forecasters were also limited to using the NWSRFS and excluding external forecasting tools, with two significant exceptions. First, WFO forecasters relied on a high degree of coordination with RFCs and even local flood control districts in their issuance of flood warnings and watches. Second, RFC forecasters cooperated with the NRCS and SRP in producing seasonal water supply outlooks, with each group adjusting their independent forecasts to create a unified product. These relationships represent precedents for more efficient incorporation of new models and data into official forecasts. However, the hydrologic research community would need to commit to producing their own operational hydrologic forecasts.

3.6.6 Forecast Performance

The meteorologic community has a long history of evaluating forecasts (Clayton [1889] is an early example), but readily available information about the quality of actual weather forecasts is still rare beyond reviews of specific events (Brooks et al., 1997). Detailed evaluations of weather forecasts have not typically focused on the Southwest, but instead have included the region in larger analyses for the Interior West and Central or Southern Rocky Mountains. NWS forecast groups agreed that better verification of forecast performance was needed, especially at local scales (HPC, 1997; Junker, 1998). Conditions in the Southwest, however, make forecast assessment difficult. Sparse data networks and spatial heterogeneity of meteorologic conditions can make a mockery of claims for high confidence in "observed" values. Comparison of individual forecast techniques is complicated by differences among model formulations. For example, because each model used unique terrain descriptions that could be vastly different, forecasted temperatures referred to different locations and elevations. Finally, constantly evolving model formulations suggest that evaluations can become outdated quickly.

Climate forecast evaluations have periodically appeared in the scientific literature (Bettge et al., 1981; Priesendorfer and Mobley, 1984; Livezey, 1990; Murphy and Huang, 1991; Livezey et al., 1997). However, with some exceptions (e.g., Lehman, 1987; Mjelde et al., 1993) the evaluations were framed for researchers and forecasters rather than users, and did not distinguish among regions within the Southwest; others supported internal operations and were not broadly distributed (e.g, SRP, 1998) CPC outlooks posted on the Web included maps of skill for some forecast techniques, but they were cryptic, offered no interpretive information, and reviewed what constituted only partial input to final forecasts. The latter limitation exists for any evaluation focused only on a single technique (e.g., Unger, 1996a,b; Peng et al., 2000). CPC also provided quantitative evaluations of each official forecast on their Web site, but results reflected conditions across the entire conterminous U.S., without regional breakdowns. Reviews of overall climate outlook performance designed for the general public (CPC, 1995; WRCC, 1998) described elements of expected performance in the Southwest, but lacked quantitative assessments. Goddard et al. (2000) reviewed climate forecasting capabilities, although the techniques were not associated with specific forecast providers or products. Other evaluations addressed forecast performance only for short periods, e.g., during the 1997-98 El Nino event (Leetma, 1998; Barnston et al., 1999; Mason et al., 1999; OGP, 1999; Pagano et al., 1999).

As long-term forecasts, climate outlooks pose special difficulties for quantitative evaluation. First, climate outlooks concern only average temperatures and total precipitation over an entire forecast period. They say nothing about daily, weekly, or even monthly extremes within a 3-month forecast period, or whether precipitation will occur as many small, or a few large, events. However, in the semi-arid Southwest, seasonal precipitation can be defined by a single event, such as Hurricane Nora in 1997 (Pagano et al., 1999). Second, limited samples compromise even the most mathematically rigorous analyses. Spatial and temporal autocorrelation reduces effective sample sizes further, while forecast technology changes faster than sufficient data can accumulate.

The hydrologic community does not have a strong tradition of evaluating operational forecasts. Workshop participants recalled failed efforts in the late 1970s to compare operational performance of hydrologic models and forecasts. Conflict arose over the basins, data sets, evaluation periods, and techniques to use. The overall sense was that hydrologists and their institutions had too much at stake, professionally and financially, to risk their techniques proving inferior to others in a head-to-head comparison. Thus, most evaluations have focused on alternative techniques (e.g., McCuen et al., 1979), not operational products.

Seasonal water supply outlooks inherently provide some evaluation information, through the various exceedance quantiles, because they are based on the standard error of regression calibration. In addition, the CBRFC and NRCS provided annual reviews of the past season's outlooks and actual conditions (e.g., CBRFC, 1991), although without addressing performance over more extended periods. The most recent evaluation of operational hydrologic forecasts dealt with seasonal outlooks issued through 1980 (Shafer and Huddleston, 1984), using simple statistics (e.g., error, bias) and treating the 50% exceedance forecasts as deterministic, not probabilistic, values. NWS has developed procedures for evaluating experimental ESP forecasts (Perica, 1998), but no assessments had been completed for Southwest watersheds during the survey period. Comprehensive evaluations of historic hydrologic forecasts are limited by lack of computerized data and documentation of model details (e.g., changes in the regression equations). For seasonal-scale forecasts, potential assessments are also limited by small effective sample sizes, because few outlooks are issued each year and there is high correlation among conditions within a season.

3.6.7 The Future of Forecasting

The evolution of computer power and remote sensing of oceanic, atmospheric, and land conditions have produced significant shifts in the philosophy and practice of weather and climate forecasting, although not yet for hydrologic forecasting. The meteorologic forecasting community incorporated spatially variable approaches to dynamic conceptual modeling, while conceptual hydrologic models were still lumped applications, treating large regions as a single homogeneous unit. While the availability of geographic information systems, digital models of terrain characteristics, and satellite remote sensing had fostered substantial research to develop distributed hydrologic models, the models were far from being used operationally.

Research focused on interactions among oceanic, atmospheric, and land systems has resulted in the incorporation of limited coupling into operational forecasts. In particular, SSTs over the Pacific Ocean were used in several GCMs to affect climate forecasts over continental areas, and ENSO phenomena were incorporated into some statistical equations forecasting water supply in the Southwest. However, other large-scale phenomena (e.g., Pacific North American and Southwest trough circulation patterns, Pacific decadal oscillation), while recognized as having important consequences for Southwest hydroclimatology (Cayan and Peterson, 1989; Redmond and Koch, 1991; Cayan, 1996; Woodhouse, 1997), were incorporated into operational forecasts in very limited ways or not at all.

Some nested models were being used for weather forecasts, but many alternative implementations remained to be explored (e.g., use of one-way or two-way feedbacks between nested models, nesting with more than two tiers of models). Nesting of models with different spatial coverage and resolution is wrought with complexities related to appropriate linkages of processes and other issues. In contrast, temporal nesting is conceptually straightforward, but was largely neglected by forecast operations during the survey period. While operational forecasts were made for time scales ranging from minutes to several months, there were no explicit connections between them. Further, while forecasters generally recognized that the accumulation of short-term forecasts should be consistent with longer-term forecasts, both production and evaluation of forecasts generally neglected nested time intervals.

A reasonable vision of forecasting over the extended future is for increasing complexity and interconnectivity of all phases of modeling. A forecast system of the future might be expected to include incorporation of a greater variety of data; coupling between oceanic, atmospheric, and hydrologic processes; nesting across multiple spatial and temporal scales; and updating of forecasts by assimilation of recent observational data. Further, the future of forecasting is likely to include a larger number of techniques, both statistical and dynamical, empirical and conceptual. The best means for integrating and communicating diverse forecasts will likely become an increasingly important question for both forecasters and forecast users.

Large research programs, with joint participation by many research groups, are focused on developing the next generation of forecast tools. However, based on the slow rate of transition of research into hydrologic operations, it is likely to be many years before the research programs will result in new operational hydrologic forecasts. Theoretically, there are significant opportunities for relatively rapid improvement of operational hydrologic forecasts based on recent improvements in climate forecast skill. However, because hydrologic research programs are generally devoted to the next generation of forecast tools and exclude current operational techniques, those opportunities have not yet been realized.

3.7 RECOMMENDATIONS

Review of the weather, climate, and hydrologic forecasts available for the Southwest, along with institutional considerations, suggests a range of opportunities for improving the production, delivery, and use of forecast products. The following recommendations require interdisciplinary collaboration, not just between the physical science research community and operational forecasters, but with current and potential forecast users and social scientists as well.

3.7.1 Product Content and Communication

Qualitative aspects can be as important as any quantitative attribute in affecting how users interpret, apply, and ultimately judge forecast products (Nicholls, 1999). This survey revealed a wide array of methods and formats used to communicate forecasts. Discussions with study participants revealed that even those with technical backgrounds were consistently misinterpreting some products. Surveys, structured discussions, and other innovative approaches (National Research Council, 1999b) should be used to comprehensively assess forecast qualities and influence development of products that foster easy, accurate, and reliable interpretation. Among the issues that should be addressed include:

- visualization of forecasts, both spatial (e.g., climate outlooks) and temporal (e.g., water supply outlooks),
- communication of probabilistic forecasts in ways that present likelihoods across entire distributions and relative to base probabilities (e.g., IRI climate forecasts, water supply outlooks),
- presentation of ancillary information (e.g., text discussions, historical data, local climatologic distributions), and
- designation of forecasts as official, operational, experimental, or research products.

Further, while potential users had opportunities to access a variety of products, there was little supporting information to help them choose which products would be most appropriate for their specific needs. Decision makers should be encouraged to establish ongoing relationships with forecast providers, particularly WFOs. The complexity of some products and the diversity of potential users suggest an intermediary role for other organizations as well, as translators, advisors, and to develop more useable products. Toward that end, efforts should focus on how specific products are used and establishing priorities for fulfilling users' needs for new products. During the 1997-98 El Nino event, Pagano et al. (1999) assessed decision makers' use of hydroclimatic forecasts in the context of anticipated water surplus in the Southwest. Needed still, however, are similar studies conducted during La Nina conditions to address slowly developing drought conditions lacking easy action options.

Finally, this 2-year survey provides only a panoramic snapshot of forecasts available for the Southwest. Since the end of the study period, new forecast products and providers have emerged on the scene, e.g., excessive heat outlooks issued by the CPC. In another case, a private company began selling attractive, but incorrect, reinterpretations of CPC climate outlooks. Additional surveys should be repeated periodically to assess the evolution of forecast products and their delivery.

3.7.2 Modeling Capabilities

Large ongoing programs in atmospheric and hydrologic research make clear that current modeling capabilities do not provide sufficient predictive capabilities for many conditions and purposes. In the Southwest, where global- and continental-scale climate processes may sometimes be less significant than regional land surface-atmosphere interactions, regional climate models would be useful for downscaling climate outlooks or increasing the frequency of non-climatology climate forecasts, especially for the summer monsoon season. The modeling recommendation rated highest at the forecast assessment workshop called for more effectively incorporating climate forecasts, and their variable quality, into statistical water supply outlooks. Additionally, studies should evaluate the potential for frequent areal measurements of snow conditions (e.g., from the NWS National Operational Hydrology Remote Sensing Center) to improve hydrologic forecasts using operational statistical and conceptual models.

3.7.3 Forecast Evaluation

Organizations that make forecasts publicly available should also provide publicly available evaluations of forecast performance. Assessments of historic forecasts provide users with a quantitative basis for forecast credibility and can demonstrate product improvement over time, enhancing the potential for decision makers to respond appropriately to both anomalies and forecasts of their occurrence (Sarewitz et al., 2000). However, this survey found that forecasts were rarely accompanied by clear quantitative assessments of past performance. Recent evaluations of CPC climate outlooks, completed subsequent to the survey period (Wilks, 2000, Hartmann et al., 2002a), represent important progress but are not accessible to general users when they acquire forecasts. From a user's perspective, a better alternative would be an interactive Web site that allows users to evaluate past forecasts that cover the periods and lead times relevant to their situation, using multiple forecast performance measures that reflect their sensitivity to different forecast qualities.

For operational forecasters, frequently updated evaluations can help in calibrating the uncertainty they attribute to a final product. For the research community, evaluations can identify situations where forecasts have been consistently inaccurate, suggesting unique situations and potential model improvements. Hindcasts, whereby predictions are made of the past in a simulated operational setting, are useful for individual forecast techniques, but less so for products that incorporate forecaster subjectivity. However, hindcasts could effectively assess the objective criteria for assigning climatologic probabilities in the CPC outlooks, as well as hydrologic forecasts made using ESP or statistical regressions.

Finally, forecasters and the research community should jointly establish an archive of operational products and ancillary information. The NWS Surface Records Retention System stores all NWS products issued through their official channels, but it was designed for accessing forecasts related to specific events, has high retrieval costs, and was uniformly seen by NWS personnel as ineffective for extracting hypertemporal records. However, the transient nature of many forecasts and the lack of archived details about their production preclude evaluation across a broad range of products. Without periodically updated evaluations that are accessible to users, the scientific and forecasting communities risk that inevitable failures of specific forecasts will engender persistent skepticism, even as scientific understanding and forecast techniques improve.

CHAPTER FOUR

DEFINING A STAKEHOLDER DRIVEN HYDROCLIMATIC RESEARCH AGENDA

4.1 INTRODUCTION

This chapter presents a stakeholder driven research agenda focused on hydroclimatic forecasts that has been developed as part of the CLIMAS project. This chapter has three objectives. The first is to provide some background on stakeholder driven research in hydroclimatic research and the unique role of forecasts in linking science and society. The second is to describe the elements of the research agenda and how they reflect stakeholder input. The third is to explain how the agenda contributes to the larger CLIMAS project as well as other hydroclimatic research efforts.

4.1.1 Research Program Perspectives on Stakeholder Driven Research

As mentioned in Chapter 1, stakeholder driven research has not been standard practice in the physical sciences. Rather, separation of basic and applied sciences has been the rule, including in hydroclimatic research. For example, in addressing their mandate to define a comprehensive integrated program to address global change, the Earth Systems Science Committee (1988) drew clear boundaries between basic and applied research. Interconnections between regional and global climate and socioeconomic impacts were seen as important motivations for expanding earth science research investments. However, the group explicitly excluded discussion of interconnections and impacts. The group considered those topics outside the group's mandate and expertise, and said impacts and potential responses should be addressed in a separate program. More recently, the U.S. Global Change Research Program has focused on basic research rather than applied or user-inspired research, even though explictly directed to produce "useable science" by Congress (Pielke, 1995, 2001).

Science programs without a stakeholder orientation can certainly produce quality science and improved understanding of physical processes (Oreskes, 2000; Pielke, 2001). However, incorporation of stakeholder perspectives potentially can substantially alter the specific scientific questions addressed and research activities undertaken within a program. For example, in his review of the scientific challenges related to management of the Colorado River, MacNish (1992) identified clearly how different perspectives can be manifested in research programs. Research targeted at managing resource development in the Lower Colorado River Valley has focused on simple hydrologic budgets, supported by sophisticated identification of water use (e.g., using satellite imagery for estimating vegetative consumptive use of water). In contrast, resource preservation motives require research to reveal complex hydrologic processes and interactions, including channel hydraulics, sedimentation, and water quality.

Many recent reviews of scientific research programs and objectives have mentioned the need for stakeholder driven research. Table 4.1 lists comments from several reviews related to hydroclimatic research. The terminology used and the relative emphasis placed on considering stakeholders varies, but even calls for benefit-cost studies to determine research directions reflect dissatisfaction with traditional practice (i.e., the separation of basic and applied science, and the linear relationship between

Table 4.1. Perspectives on stakeholder driven research.

Research Program and Perspective
U.S. Global Change Research Program (Subcommittee on Global Change Research, 1997) "The communication must also be a dialogue, in which the presentation of scientific information is appropriate to the knowledge and concerns of the recipient, and in which those expressed concerns in turn feed back into the research enterprise..."
Global Energy and Water Cycle Experiment Continental-Scale International Project (GCIP) (National Research Council, 1998a) "To ensure that GCIP's modeling improvements and data products are useful to the water resources management community, it is important that a dialogue be established." "It is highly recommended that the GCIP program develop a strategy for (1) familiarizing the water resources management entities... with the program and (2) seeking their input and advice on GCIP modeling and data activities and how these could be made more useful for their purposes."
Atmospheric Sciences (National Research Council, 1998c) Need "interdisciplinary studies of the benefits and costs of weather, climate, and environmental information services", to identify "which new directions in atmospheric research and services will provide the most benefit to the public and private sectors".
Weather Forecasts (National Research Council, 1999a) Need to "more agrressively support and capitalize on advances in science and technology to increase the value of weather and related environmental information to society."
Climate Forecasts (National Research Council, 1999b) "The utility of forecasts can be increased by systematic efforts to bring scientific outputs and users' needs together." "A key to making climate forecasts more socially useful is to develop links between those making the predictions and those who can benefit from them."
U.S. Global Change Research Program: Hydrologic Sciences (National Research Council, 1999c) "Increasing emphasis ... fostering participatory, interactive research involving researchers, decision-makers, resource users, educators, and others..." "Hydrologic science community should adopt a stronger sense of responsibility for delivering timely and relevant scientific tools." "Effective two-way knowledge transfer between researchers and the many [stakeholders] is clearly needed."

Table 4.1, continued. Perspectives on stakeholder driven research.

Research Program and Perspective
U.S. Global Change Research Program: National Assessment (National Assessment Synthesis Team (2000)
Need "close partnership of natural and social scientists with local, regional, and national stakeholders"
Recommended acceleration of activities focused on integrating science with the needs of decision makers
Offered regional integrated assessments as examples of innovative approaches
U.S. Global Change Research Program: Water Cycle (Hornberger et al., 2001)
"A knowledge transfer initiative should be designed to integrate users needs into the development of the research agenda and to ensure that research results are provided in a form useful for users."

science and society, as shown in Figure 1.1). While the need for more effective integration of and response to stakeholders is broadly acknowledged, few specifics are offered about how to engage stakeholders, adapt research programs, or gauge success. An exception is the report, *Making Climate Forecasts Matter* (National Research Council, 1999b), but it focuses mostly on methods for engaging stakeholders and determining the impacts of climate variability and forecasts.

4.1.2 Requirements for Stakeholder Driven Research

By necessity, stakeholder driven research agendas must start off relatively open-ended (National Research Council, 1999b). The CLIMAS project began with a general goal of being responsive to regional needs for scientific research and information, in ways that enable stakeholders to effectively respond to hydroclimatic events and changes. In addition, the project was intended to be interdisciplinary, participatory, iterative, and integrative, with the latter covering three dimensions: (1) integration of researchers and stakeholders, (2) disciplinary integration of CLIMAS researchers, and (3) end-to-end integration of research topics (e.g., from climate information to vulnerability to response) (Bales and Morehouse, 2000). Discussions occurring throughout the CLIMAS project provided the basis for several over-arching principles that were to guide development of research agendas and activities, including:

- Research agendas should directly reflect stakeholder input. Too often in other projects, stakeholders are not invited to be part of the research design.

- Outcomes from the research program should benefit groups that were part of the research process. Too often in other projects, groups that are studied fail to benefit from research that is conducted on them.
- Outcomes from the research program should benefit different stakeholder groups equitably. Too often in other projects, research benefits go first to groups with the most education, money, and other resources.

Stakeholder driven research in the context of CLIMAS was anticipated to be an on-going process requiring (1) the development and maintenance of interdisciplinary capacities and infrastructure, and (2) products that facilitate effective decision making. While data and models clearly comprise part of the first element, the human dimension is also important. The process requires researchers to build and build upon relationships with stakeholders, some of whom may be difficult to cultivate (e.g., groups skeptical of science or government). Thus, when significant hydroclimatic events begin to develop (e.g., drought related to La Niña), the human capacities and infrastructure are readily available to respond quickly, effectively, and proactively.

The second element concerns products that can ultimately link hydroclimatic variabilty, relevant impacts, and potential response options, in the context of values held by the stakeholders (e.g., watershed protection, profit maximization, maintenance of lifestyle). Initial interactions with stakeholders are aimed at determining what products are needed, when the products would be most useful, and how the products can be communicated effectively. Of course, while stakeholders may express their desires for products, the research community can only respond within the limits of scientific and technologic capabilities. Clear communication of limitations is essential to control expectations (Pielke and Glantz, 1995) and, perhaps counterintuitively, build confidence in the products (O'Grady and Shabman, 1990).

Within the stakeholder driven research agenda, scientists can conduct research to evaluate observations or improve understanding of physical processes. However, researchers should be able to link their studies to questions or needs identified by stakeholders. In addition, the research community must commit to product development and use. Efforts must help stakeholders understand new information, appreciate its relevance and implications, and especially for new types of information, incorporate it into decision making processes. Research results can be made more useful by targeting specific locations, using formats and explanations that can be properly interpreted by non-specialists, and demonstrating potential applications (National Research Council, 1999b).

4.1.3 Focus on Forecasts

Forecasts offer a potentially strong link between science and society. Within the hydroclimatic research community, the ability of a mathematical model to predict conditions at specific times and locations (i.e., forecast) is considered a test of scientific understanding about the relevant physical processes and their interconnections (e.g., Subcommittee on Global Change Research, 1997; National Research Council, 1998a). For society, forecasts have broad relevance because, whether explicitly recognized or not, most decisions related to natural resource management rely on of some sort of weather, climate, or hydrologic forecast. Within the CLIMAS program, hydroclimatic forecasts were identified early as being potentially important for reducing stakeholder vulnerability to climate variability.

Sarewitz et al. (2000) provide a comprehensive critique on the use of predictions for setting policies and making decisions related to a variety of natural resource issues. Certainly, predictions may not always be required, or even important, to develop successful policies or make good decisions (Brunner, 2000; Jamieson, 2000). For example, policies related to climate change issues may benefit more from other kinds of scientific information (Rayner, 2000; Sarewitz and Pielke, 2000a,b). However, it is clear that, although their potential has not been fully realized, forecasts can be important for informing policies and decisions related to hydroclimatic variability at interannual and shorter scales (Hartmann and Donahue, 1990; National Research Council, 1998b, 1999b; Hooke and Pielke, 2000; Changnon, 2000c).

4.2 THE HYDROCLIMATIC RESEARCH AGENDA

When the CLIMAS project began, the hydroclimatic research agenda was indeterminate. Many potential topics (Table 4.2) were identified in the original proposal (Bales et al., 1997) and in subsequent discussions throughout the project's first year. However, as a result of stakeholder input and the review of weather, climate, and hydrologic forecasts for the Southwest, the following agenda emerged as a potentially effective means for linking research and the needs of stakeholders.

Table 4.2. Potential areas of hydroclimatic research discussed in the first year of the CLIMAS project.

Research Topic
Observations and Analysis
Construction of a hydroclimatologic data base, including streamflow, groundwater, snowpack, reservoir levels and releases, precipitation, temperature, evapotranspiration
Analysis of hydroclimatic variability at various spatial and temporal scales, including spectral analysis and comparison of monsoon and winter variability
Develop statistical indices to describe seasonal hydroclimatic variability (e.g., transitional probabilities between conditions [e.g., wet/dry], storm duration, time between storms)
Identification of El Niño-Southern Oscillation signals in regional hydroclimatic variables
Identification of dominant hydrologic processes contributing to variability of water resources availability
Determination of dynamic impacts of topography, vegetation, and land use on hydrologic process spatial variability
Development of paleoclimatologic reconstructions, including precipitation, temperature, streamflow, soil moisture
Development of historic hydroclimatic data targeted on specific events (e.g., the droughts of the 1940s and 1950s, the 1983 El Niño event) for case study of stakeholder response
Comparison of detailed spatiotemporal hydroclimatic datasets (e.g., data from the Walnut Gulch research watershed versus the Vegetation/Ecosystem Modeling and Analysis Project [VEMAP; Kittel et al., 1995, 1998])
Examination of impact of snowmelt on recharge of groundwater supplies, including the relevant processes and impacts of variability in snow conditions
Hydroclimatic Modeling Development
Development of predictive tools linking large-scale climate forcing to regional-scale hydroclimatic variables
Creation of scenarios, including reconstruction of naturalized streamflows and climate change scenarios (e.g., from modeling or analogs)
Forecast Assessment
Assessments of hydroclimatic forecasts
Obtain stakeholder reactions to experimental forecasts
Assessment of historical climatic information, including use of historic statistics in decision making along the lines described by Hartmann and Donahue (1990)
Assessment of climate information delivery systems
Downscaling of climate forecasts and change scenarios to provide localized forecasts and change scenarios
Development of simple methods for stakeholders to interpret hydroclimatic data and make their own predictions
Creation of extended time series of pseudo-hydroclimatic forecasts (e.g., hindcasts made in a simulated operational setting) and using those to examine stakeholders' decision making processes

4.2.1 Elements of the Program

Figure 4.1 illustrates the research agenda developed for hydroclimatic forecasts in the context of the CLIMAS project. The agenda is comprised of a highly interconnected series of research activities that provide multiple avenues for advanced research products to rapidly, efficiently, and effectively reach stakeholders. Forecasts are considered a locus of integration between hydroclimatic science research and stakeholders. The agenda provides a framework for an ongoing process of generating, archiving and evaluating forecasts that enables rapid assessment of new scientific information reflected in forecasts, as it is developed through CLIMAS or other research programs, in ways that have meaning and applicability for stakeholders. Details of each research activity are available in CLIMAS documents (e.g., CLIMAS, 2001a) and not repeated here.

Forecasts

Seasonal climate and water supply outlooks are central elements of the research agenda. The forecasts provide a means for linking advances in observations (e.g., snow conditions) and scientific understanding of physical processes (e.g., hydroclimatic models) with expressed needs of stakeholders. First-phase research activities are focused on evaluations of forecast quality (Table 4.3). Forecast evaluations explicitly reflect the seasons, lead times, variables, and criteria important to decision makers, and represent a direct response to stakeholder comments. Targeted evaluations enable better

Figure 4.1. Schematic of stakeholder driven hydroclimatic research agenda emphasizing forecasts and their assessment as the link between science and society.

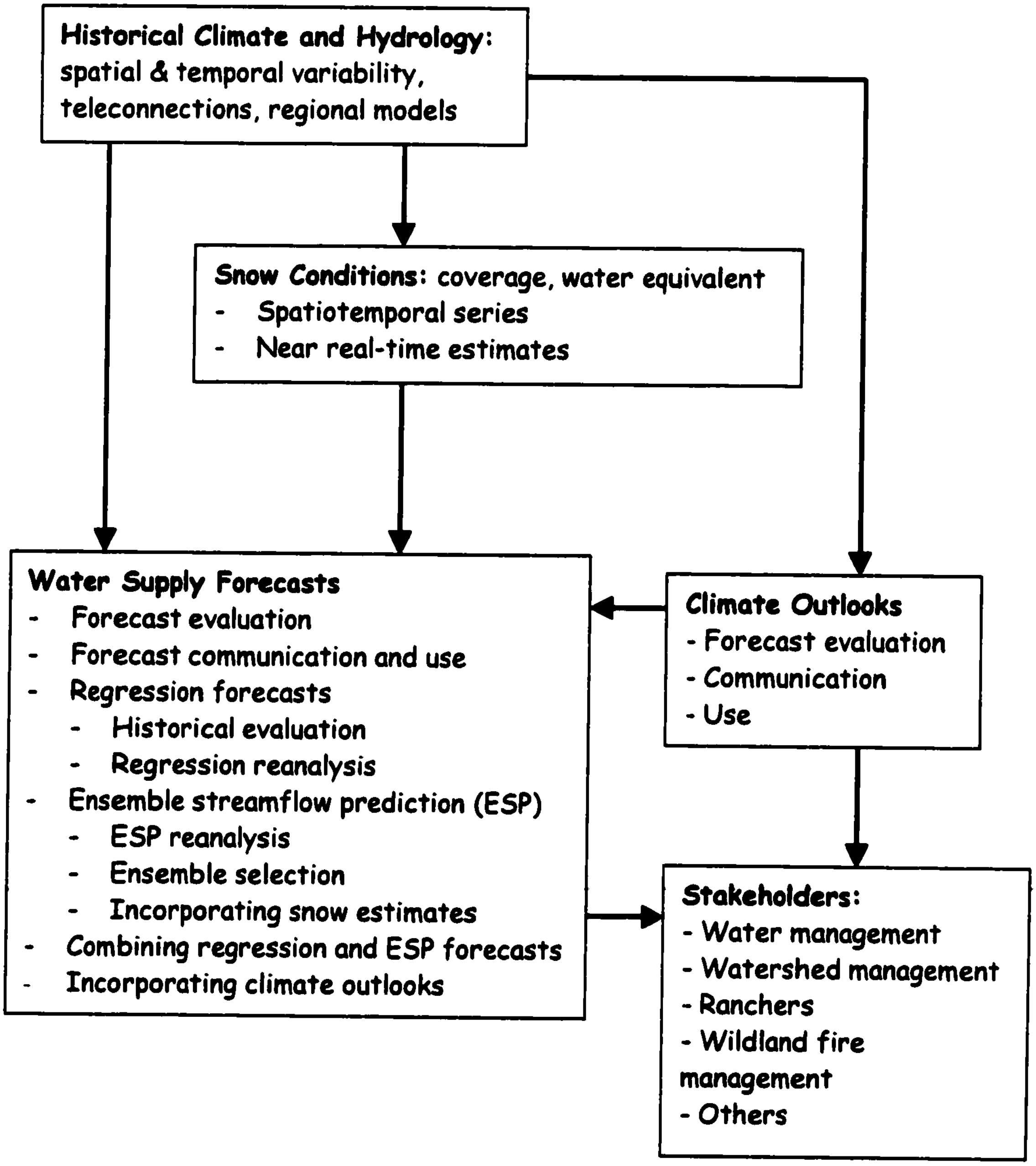


Table 4.3. Evaluation methods and research questions for elements of the forecast process (adapted from Hooke and Pielke, 2000).

Element of Forecast Process	**Outcome**	**Evaluation Criteria**	**Evaluation Methods**
Forecast	Forecast products	Measures of quality	Quantitative comparisons (e.g., Whitaker et al., 2000a,b; Franz, 2001; Hartmann et al., 2002a)
Communication	Forecast guidance, ancillary information	Information transfer, correct interpretation	Surveys, interviews, structured discussions (e.g., Chapter 2; Pagano, 1999, 2001, 2002)
Use	Decisions	Value (monetary and otherwise)	Descriptive decision studies, decision models, interviews, structured discussions (e.g., Pagano, 1999, 2001, 2002)

Intersection of Forecast Elements	**Relevant Research Questions**
Forecast/Communication	What does the prediction mean in operational terms? How reliable is the prediction, and how is uncertainty conveyed?
Forecast/Use	What ought to be predicted? How are predictions actually used?
Communication/Use	What information is needed by the decision maker? What content or form of communication leads to the desired response?

communication of scientific uncertainty and make concrete the limitations of predictive modeling. Further, having a series of evaluations based on current technologies provides a foundation for accurately assessing the subsequent contributions of advanced research programs, observation technologies, and modeling capabilities to stakeholder decisions.

Climate forecasts are a central focus of the research agenda because they have such broad applicability for such a wide variety of stakeholders. Climate forecasts of immediate interest include the official CPC forecasts, experimental forecasts (e.g., from IRI), and research forecasts that may evolve within CLIMAS or elsewhere (e.g., from the Experimental Climate Prediction Center). Evaluation of seasonal climate forecasts has advanced to the stage (see Chapter 5) that second-phase interactions with stakeholders have been initiated, with the goal of presenting evaluation results and obtaining feedback on the effectiveness of the analyses, criteria for evaluation, and effectiveness and understandability of the graphical products and explanations.

Water supply forecasts are also a central focus of the agenda because they play a significant role in the operation of many water management agencies, including reservoir regulation for seasonal flood control (Burke and Stevens, 1984) and water allocation to users in times of shortage (Glantz, 1982); their use is, in some cases, required by law. Research activities are organized to enable incremental improvements in water supply forecast capabilities, with quantitative demonstration of improved forecast performance at each step. The forecasts of immediate interest are the historical official water supply outlooks, the current regression equations used to generate official water supply outlooks, and experimental forecasts generated using an ensemble approach with a dynamic rainfall-runoff model. Whitaker et al. (2000a,b) presented initial results of evaluations of historical forecasts. Franz (2001) used the evaluation framework presented in Chapter 5 to evaluate probabilistic ESP forecasts for 14 locations in the Colorado River Basin.

Improvements of the ESP forecasts are also part of the research agenda. Current CBRFC experimental ESP forecasts attribute equal probability of occurrence to each ensemble member. However, there are significant research questions about the appropriate organization and weighting of ensemble members.

With several approaches available for forecasting water supplies, and more in development, the issue of combining forecasts becomes important. Interactions with agencies responsible for operational seasonal water supply forecasts have revealed that one reason for the slow transition to new technologies in hydrologic forecasting is a reluctance to abandon technologies, especially those with a long tradition and several perceived advantages over new alternatives. Following the example set by the meteorologic forecasting community, combining current and new forecasts (e.g., regression and ESP water supply forecasts) into a single product offers one means for more rapidly incorporating new technologies.

Observations and Analyses

Within the agenda, there is a role for scientific research to be driven by improved observations or scientific questions, to the extent that the research is then used to improve statistical or conceptual models, and then predictions. For example, priority activities promising near-term advances include the development of high quality spatial time series of snow water equivalence estimates. Quality estimates of snowpack water storage offer the potential for improving regression-based and ESP water supply outlooks. In addition, the estimates will play an important role in the validation of advanced hydrologic models, including highly distributed dynamic land surface-atmosphere models, and their initialization when used in a forecast setting.

Stakeholders

The research agenda in Figure 4.1 is not limited to assessment of forecast products. Rather, for each type of forecast, issues of communication and use are to be addressed as well. Table 4.3 lists methods suggested by Hooke and Pielke (2000) and examples from this work that have been used for evaluating each element of the forecast process. As Hooke and Pielke (2000) stress, elements of the forecast process are highly interconnected, and should not be addressed in isolation. Table 4.3 also lists research questions related to interconnection between elements of the forecast process. While multiple techniques exist to evaluate forecast communication and use, none is entirely adequate (National Research Council, 1999b). Structured discussions (e.g., workshops, conferences) appear to offer significant advantages over other techniques, especially in efficiency and flexibility. However, structured discussion methods are not yet well developed (National Research Council, 1999b) and should be the subject of research themselves, within CLIMAS and in extrapolation to other efforts.

4.2.2 Integration with Activities in the Climate Assessment for the Southwest Project

Figure 4.1 shows only unidirectional linkages between scientific research activities and stakeholders, because the emphasis here is on adaptation of the physical science research agenda. However, these activities are embedded in the larger context of iterative stakeholder interaction (e.g., Figure 3.4). The activities are intended to be interdisciplinary as well, using social scientists and social science methodologies for evaluating the effectiveness of communication and use of the forecasts, and evaluating the products designed in response to stakeholder input. As described in Chapter 2, the framework for and results from evaluations of seasonal climate forecasts have been presented to stakeholder groups, to check that the products indeed reflect earlier input and are understandable.

Activities within the research agenda are well matched with CLIMAS goals. The focus on current and imminent forecasts provides immediate relevance to stakeholders, while also providing a starting point for initiating conversations with stakeholders about advanced technologies and products. Providing forecast evaluations helps meet expectations generated by stakeholder interaction within CLIMAS, because the evaluations are a direct response to stakeholder requests. Because the research agenda is based on broad input from a diverse array of stakeholders, the evaluation activities should be easily extendable to other projects as well.

4.3 DISCUSSION

4.3.1 Integration with Other Projects

The interconnectivity between science and society shown in Figure 4.1, using predictions as the shared interest of scientists and stakeholders, has broad applicability. This section describes two avenues for integrating the research agenda with other ongoing hydroclimatic research programs.

The GEWEX America Prediction Project (GAPP)

GAPP is funded by NOAA's OGP as a unit within their Climate and Global Change Program, which in turn is a major component of the interagency U.S. Global Change Research Program. The Climate and Global Change Program is designed to improve capabilities "to observe, understand, predict, and respond to changes in the global environment" (NOAA, 2000). GAPP represents an evolution of the GEWEX Continental Scale International Project (GCIP). The goal of both projects is to develop capabilities "to predict variations in water resources on time scales up to seasonal and interannual as an integral part of a climate prediction system" (National Research Council, 1998a). GCIP priorities focused largely on observing and evaluating components of the global and regional energy and water budgets.

The GCIP project did not result in science usable for policy and decision making, at least by water management interests (National Research Council, 1998a). As a means to foster production of usable science, GAPP priorities are focused on (1) developing and demonstrating predictive capabilities and (2) interpreting and transferring results to water management organizations (GAPP, 2000). However, the GAPP project acknowledges that little is known about the which mechanisms are most effective for transferring scientific advances to the water management community.

The research agenda of Figure 4.1 is easily extended to include advanced predictions produced by GAPP. The agenda's emphasis on incremental evaluation, in ways that have meaning for stakeholders, would enable GAPP predictions to be clearly seen as being better, and thus, GAPP science as making societally relevant contributions. In addition, the recognition that proper interpretation by users is as important as forecast quality forms the basis for commitment to development of interpretive guides, short courses, or other material designed to improve the usability of model outputs.

The National Science Foundation Science and Technology Center for SAHRA

The SAHRA Science and Technology Center is a major research initiative funded by the National Science Foundation, with a mission to "promote sustainable management of water resources in semi-arid regions through stakeholder-driven interdisciplinary research, aggressive public outreach and strong education initiatives," (SAHRA, 2001a). The SAHRA vision is to "develop an integrated, multi-disciplinary understanding of the hydrology of semi-arid regions, and to build partnerships with broad spectum of stakeholders... so that [the hydrologic] understanding is effectively applied to the optimal management of water resources and to the rational implementation of public policy" (SAHRA, 2001b). To achieve its aims, SAHRA implemented processes to (1) monitor critical hydrologic issues, (2) identify which issues can be successfully addressed in a reasonable time, (3) coordinate and integrate interdisciplinary, multi-institutional studies, (4) bring maturing research and technologies to a state of advanced development, and (5) target resources on development of "technological and educational interventions" for improved water management (Sorooshian et al., 1998).

While SAHRA aims are similar to those of CLIMAS, although with a more targeted focus on water resources, it is implemented at a much larger scale in terms of financial resources, breadth of the issues addressed, and the number of scientists involved. Hydrologic areas of focus include (1) spatial and temporal components of the hydrologic water balance, (2) basin-scale water and solute balances, (3) functioning of riparian systems, and (4) multi-resolution integrated modeling of basin-scale hydrologic processes (SAHRA, 2001b). Other areas focus on water resources management and education and outreach (SAHRA, 2001b).

With SAHRA's emphasis on using leading-edge science to affect water management decisions and societal outcomes, the research agenda of Figure 4.1 potentially provides a model for linking SAHRA research advances with needs of decision makers. The agenda's emphasis on incremental evaluation, in ways that have meaning for stakeholders, would enable SAHRA models and predictions to be clearly seen as advances and thus as appropriate for informing management practices and policies. SAHRA's broad agenda also offers the potential for testing the role of predictions in decision making in diverse settings.

4.3.2 Designing and Implementing Stakeholder Driven Research

Was it essential that stakeholders help determine the research agenda? Clearly, at the project's beginning, there were many potential avenues for natural science research aimed toward reducing socioeconomic and environmental vulnerability to hydroclimatic variability. The agenda's focus on improving seasonal water supply forecasts recognizes that scientific questions and improvements in predictability are important, irrespective of stakeholder concerns. However, the agenda's focus on forecast assessment and evaluation directly reflects concerns shared among diverse stakeholders. Without considering stakeholder input, improved predictions are likely to fare no better than recent advanced products, remaining underutilized due to the skepticism or misinterpretation of potential users.

In this project, early research activities focused on basic issues of forecast assessment and evaluation, i.e., identifying important issues (e.g., interpretation) and developing a framework for evaluating forecast quality. Because these issues relate more to stakeholder perceptions about forecasts than improving hydroclimatic predictability, one may question whether the resulting stakeholder driven research agenda is more concerned with the communication of science or the packaging of products rather than advancing fundamental understanding. The agenda also focuses on incremental improvements in seasonal water supply forecasts that are, or can be, issued operationally, reflecting opportunities for scientific advancements not addressed by other hydroclimatic research programs. However, the extant gap between the state of stakeholders' ability to interpret and use hydroclimatic forecasts and the state of hydroclimatic science and predictability is so significant that the former must be addressed before improved predictions can effectively integrated into resource management practices and policies on a broad scale.

Further, by viewing stakeholder driven research as an ongoing process, the agenda is seen as evolving as well. Continued adaptation of the research agenda to reflect stakeholder input will help answer, through experience, questions about the extent to which stakeholders can, or should be allowed to, determine research directions relative to strictly scientific issues. For example, if further improvements in climatic predictability are not forthcoming, will there cease to be any need for continued interaction with stakeholders once issues of interpretation and evaluation have been resolved? The gap between forecasts and their use is so large that several iterative adjustments of the research agenda will be required before lack of improvement in predictability will become an issue. Evolving interactions with stakeholders, beyond the scope of the current research project, suggests the agenda may be adjusted further to include research to transform regional-scale seasonal forecasts into probabilitistic local-scale event forecasts (e.g., timing of first autumn frost or last spring frost) or incorporating local data collected by stakeholders.

In addition, hydroclimatic research exists in the larger context of federal efforts to reduce vulnerability to hydroclimatic variability. From that broader perspective, even if improvements in predictability were not forthcoming, changing social conditions (e.g., stakeholder sophistication and experience related to hydroclimatic forecasts, resource management policies) or technological changes (e.g., methods of delivering forecast products) would continue to affect the potential role of hydroclimatic forecasts in decision making. These changes will create opportunities for developing new products for different stakeholders or applications, regardless of the progress of hydroclimatic science and predictability.

4.3.3 Interdisciplinary Research

Within the CLIMAS project, research efforts were intended to be highly interdisciplinary, especially between the physical and social sciences. However, in the interactions that provided the rationale for design of the research agenda, hydroclimatic researchers interacted directly with stakeholders, albeit sometimes with the assistance of social scientists. Other work was entirely disciplinary, including the forecast assessment and evaluation efforts. It is appropriate to consider whether interdisciplinary efforts are really required for stakeholder driven hydroclimatic research and, if so, what are the roles of the physical and social scientists.

In the development of the hydroclimatic research agenda presented herein, social scientists had their greatest impact through establishing principles for the overall CLIMAS project, especially that research agendas should directly reflect stakeholder input and that outcomes should equitably benefit groups that were part of the research process. In addition, social scientists were essential in the design of survey instruments (e.g., for semi-structured interviews). They also organized stakeholder interactions, but only in a general sense, not involving details of the interactions. In two areas, the social scientists were able to provide little guidance: (1) designing the structured discussions and evaluating their results, or (2) providing structure or metrics for evaluating development or implementation of the research agenda. On the other hand, the participation of physical scientists, but not social scientists, was essential for successful structured discussions. In general, social scientists lacked sufficient understanding of hydroclimatic concepts to explain them to stakeholders, discuss issues with adequate depth or detail, or to answer unusual or unexpected stakeholder questions. However, social scientists will become essential as other issues are addressed, although where scientific or technical content is an issue, joint participation of physical scientists will be required. In particular, the issues requiring social scientist participation include:

- spatial and temporal visualization of forecasts,
- communication of probabilistic forecasts in ways that present likelihoods across entire distributions and relative to base probabilities,
- presentation of ancillary information (e.g., text discussions, historical data, local climatologic distributions),
- determination of essential forecast attributes; requisite performance thresholds; relationships among forecast quality, utility, and value; and the potential utility and value of forecast improvements, and
- formal evaluation of interactions between physical scientists and stakeholders.

4.3.4 Evaluating Stakeholder Driven Research

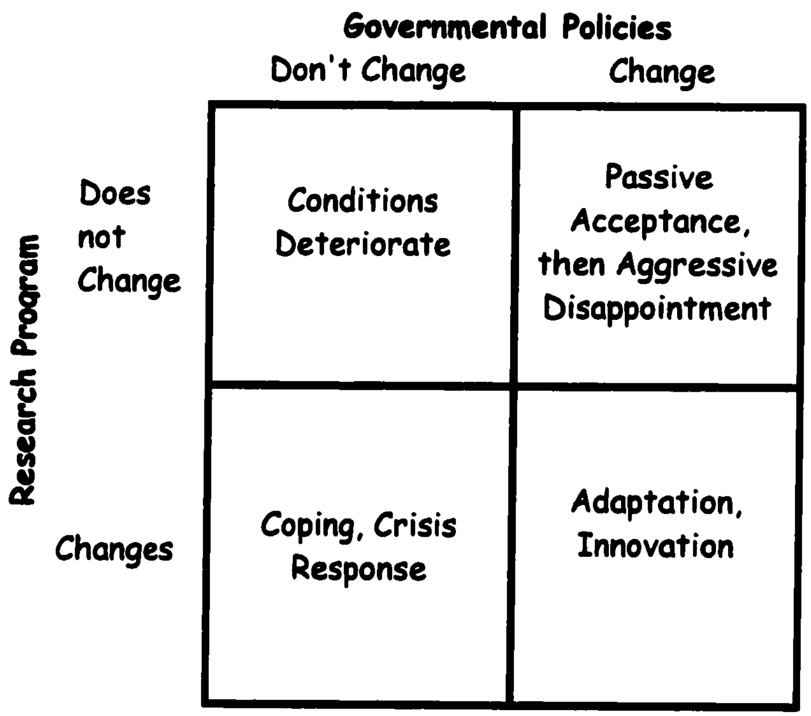
Experience in structuring and implementing stakeholder driven research is still relatively limited and not well represented in the literature (Breen et al. [1995] is notable in its uniqueness). Experience in judging the success of adapting research programs to reflect stakeholder perspectives is even more limited. On more than one occasion, when NOAA personnel with responsibilities for reviewing CLIMAS progress were asked about monitoring success of the project, their response was, generally, "We can't tell you what we're looking for. We're hoping you can help us figure that out."

Figure 4.2 offers one framework (Pulwarty, 2001c) for evaluating the whether a research program is responsive or has impacts on stakeholders via government policies. Unfortunately, evaluation requires time for research programs and governmental policies to evolve (or not), as well as for hydroclimatic conditions to vary. The case studies presented by Sarewitz et al. (2000) also offer comparative examples for beginning to address the effectiveness of stakeholder driven research related to predictions.

The formal development of the research agenda presented herein provides a starting point for external evaluation of its scientific advances, responsiveness to stakeholder input, and the balance between serving science or stakeholders. In particular, social scientists should formally evaluate the interactions between physical scientists and stakeholders to determine approaches that are particularly effective for:

- defining research problems or questions to be addressed,
- incorporating stakeholder knowledge or perspectives,
- disseminating information and implementing education activities, and
- interacting at various scales (e.g., with individuals or successively larger groups; locally, regionally, or nationally; within or across sectors; for short-term hydroclimatic events or long-terms changes).

Figure 4.2 Framework for evaluating societal impacts of research programs and governmental policies under conditions of environmental change (adapted from Pulwarty, 2001c). Entries show societal response as environmental conditions change.



How broadly applicable is the process or agenda developed in this work? No definitive answer is possible without tracking the progress and impact of the present effort and attempting to expand its application to other regions and topics. However, key elements of the process suggest that both the process and agenda are transferable to other issues and scalable to include additional regions or stakeholders. With regard to the process, iterative bi-directional interaction with stakeholders, from the outset of a program and following a public participation model, was both practical and productive. However, there are questions about whether long-term attention to a broad range of stakeholders is efficient or able to provide equitable opportunities for diverse groups to benefit from research activities and products. With regard to the agenda, seasonal water supply forecasts have broad applicability throughout the U.S. West, although less so elsewhere. However, the role of forecast assessment and evaluation has broad applicability to all types of forecasts and is easily scalable to other regions (see Chapter 5).

Finally, for time scales relevant for addressing interannual climate variability, and short-term weather variability, predictions offer a strong link between the interests of science and society. An interesting test of the extendability of the research agenda would involve incorporation of research results from other CLIMAS activities. In particular, times series of high resolution gridded precipitation and temperature data for recent (CLIMAS, 2001a) and paleoclimatic periods (CLIMAS, 2001a,b) could be incorporated in the sense that they provide historical context for the hydroclimatic forecasts. In addition, results from research on decadal scale variability (CLIMAS, 2001a) could be incorporated in the sense they may affect interannual predictability. Opportunities for testing the broad applicability of the agenda exist in the integrated assessments of climate variability being conducted in other regions throughout the U.S. (Pulwarty, 2001b) as well as in international programs (Bonnell, 2000). However, for other hydroclimatic issues, encompassing longer time scales and less confident scientific understanding, the connection may not be so clear. Issues of long-term change (e.g., climate change, regional population growth) may be better served by focusing on scenarios rather than forecasts. In that case, the iterative interactive process would likely still be useful, but not the research agenda itself. Issues related to the climate non-stationarity reflected by the paleoclimatologic record may also benefit from the iterative stakeholder interaction process, but not the hydroclimatic forecast research agenda.

4.4 SUMMARY AND CONCLUSIONS

This chapter presented a stakeholder driven research agenda focused on hydroclimatic forecasts, developed as part of the CLIMAS project. Seasonal climate and water supply forecasts comprise central elements of the agenda, while hydroclimatic forecasts in general serve as the link between stakeholders and advances in observations (e.g., snow conditions) and scientific understanding of physical processes (e.g., hydroclimatic models). The hydroclimatic forecast agenda fits within the overall CLIMAS research project and can potentially help other projects link their scientific research activities with stakeholders as well.

The agenda and its implementation in the CLIMAS project serve as a test case for adapting scientific research activities to stakeholder needs. Case study analysis or other social science research methods should be used to evaluate the research agenda and its activities. Within CLIMAS, extension of the agenda to address paleoclimatological variability through statistics of hydroclimatic conditions offers an avenue for testing the generality of the agenda. The GAPP, SAHRA, and other RISA projects offer good opportunities for comparative study or tests of extending the agenda to other stakeholders, broader groups, or different issues as well.

CHAPTER FIVE

EVALUATING SEASONAL CLIMATE FORECASTS FROM STAKEHOLDER PERSPECTIVES

5.1 INTRODUCTION

Seasonal climate forecasts have long promised the potential to improve natural resource management by enabling planning and implementation of proactive measures to mitigate or exploit predicted conditions (Namias, 1968; Nicholls, 1980; Changnon and Vonnhame, 1986). However, they have often played only a marginal role in real-world decisionmaking (Changnon, 1990; Sonka et al., 1992; Pulwarty and Redmond, 1997; Callahan et al., 1999; Pagano et al., 2001, Pulwarty and Melis, 2001). Consideration of climate forecasts appears to have advanced during recent ENSO events. The seriousness with which water and emergency management agencies regarded the 1997-98 El Niño forecasts was in part due to El Nino's relatively strong teleconnections, including a history of exceptional floods and droughts (OGP, 1999; Changnon, 2000b; Pagano et al., 1999). The subsequent strong La Nina event that produced two consecutive dry winters in the southern U.S. continued to hold the attention of water management agencies, while ranchers and wildland fire management agencies began to express interest in improving resource management through use of seasonal climate forecasts as well (Conley et al., 1999; ISPE, 2000).

Seasonal climate forecasts are likely to become even more important as conflicts increase over limited surface water supplies, evolving timber and grazing policies, and increasing energy demands in the face of stable supplies. Thorough understanding of forecast performance can enhance the potential for decisionmakers to respond appropriately to both climate anomalies and forecasts of their occurrence. Additionally, assessments of vulnerability to climate variability can benefit from evaluation of seasonal forecasts that have been, and are, available for planning proactive responses to potential extremes (Hartmann et al., 1999).

Resource managers possess a range of abilities to obtain, interpret, and use climate forecasts, with three approaches dominant (Pagano et al., 2001, 2002). Some agencies have sufficient resources to employ meteorologists, climatologists, or hydrologists that provide internal expertise. Others rely on external expertise, generally provided by federal agencies (e.g., NWS) or consultants (Changnon, 2000a). Finally, some resource managers attempt to obtain and interpret forecasts made by others (e.g., NWS), even though they have no special training. This last situation presents a real challenge to forecasting agencies: to provide useful products that can be properly interpreted even by non-specialists.

User perceptions of poor forecast quality have presented an especially persistent dilemma for climate forecasters (Changnon, 1990). A single incorrect forecast that provokes costly shifts in operations can devastate user confidence in subsequent forecasts (Glantz, 1982). Consistent communication of forecast uncertainty can, counterintuitively, increase forecast credibility (O'Grady and Shabman, 1990). Forecast performance evaluations have periodically appeared in the scientific literature (Nicholls, 1980; Bettge et al., 1981; Priesendorfer and Mobley, 1984; Barnett and Priesendorfer, 1987; Lehman, 1987; O'Lenic, 1990; Livezey, 1990; Murphy and Huang, 1991; Mjelde et al., 1993; Wilks, 2000). However, results generally are not easily applied to specific resource management decisions, because they reflect perspectives of climate researchers and forecasters, not users.

Interactions with water managers, ranchers, and wildland fire managers throughout the past three ENSO events have provided a clear and consistent message: uncertainty about the accuracy of climate forecasts precludes their more effective use (Conley et al., 1999; ISPE, 2000; Pagano et al., 1999, 2001, 2002). This study reflects an attempt to measure and communicate forecast performance in ways that are meaningful to potential users. It aims to promote discussion about forecast communication and proposes an evaluation framework that accommodates different perspectives about forecast quality and different questions of importance to users. For example, from a user's perspective, there are, in the simplest terms, two complementary questions. First, given that climate extremes will inevitably occur, what is the probability that the climate forecast system will warn the user? Second, given a specific forecast predicting an increased likelihood of some event, what is the probability that the event will actually occur? The framework addresses user questions and perspectives through consideration of the climate conditions, seasons, and lead times relevant their decisionmaking situations. Finally, because users approach climate outlooks and evaluations with different levels of training and experience, the framework incorporates progressively sophisticated criteria; they provide tradeoffs between informativeness and understandability, while offering opportunity for users to develop deeper insights about climate forecasts, credibility, and implications for decisionmaking.

5.2 METHODS AND DATA

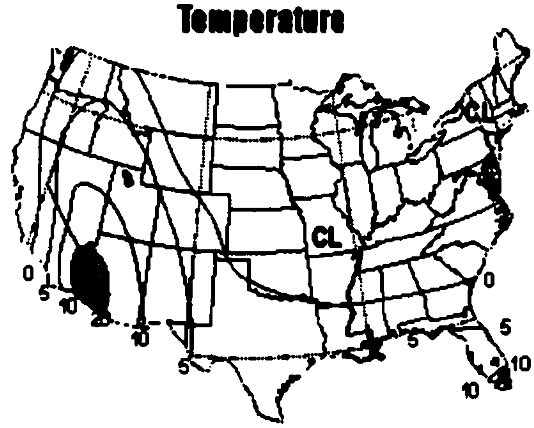
5.2.1 Climate Outlooks

Official seasonal climate forecasts have been produced by the CPC, in their current format, since December 1994. The forecasts consist of one 1-month outlook, issued with a 2-week lead time, and a series of thirteen 3-month outlooks, with lead times from 0.5 to 12.5 months. An entire suite is issued anew near the middle of each month (see *www.cpc.ncep.noaa.gov/products/predictions*). While the complete forecast package consists of several elements (Hartmann et al., 1999), two example components are presented in Figures 5.1 and 5.2: maps of surface air temperature and precipitation probability anomalies and a legend facilitating map interpretation. CPC climate outlook maps show the likelihood of occurrence, expressed using probability anomaly contours, for average air temperature or total precipitation over the forecast period to fall within the upper, middle, or lower third of conditions defined by the 1961-1990 historical record. A climatological probability (i.e., a zero probability anomaly outlook) indicates equal chance (33.3%) that conditions will fall within any of the historical tercile categories. Rules for shifting probabilities among terciles are explained in the forecast legend.

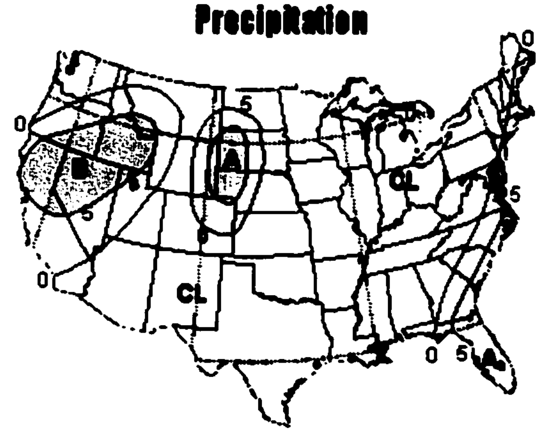
All data for the evaluations described in the following sections were graciously provided by the CPC. The forecast dataset includes outlooks issued December 1994 - October 1999. It was created by digitizing historical seasonal temperature and

Figure 5.1. Example official seasonal climate outlook produced by the National Weather Service Climate Prediction Center. Outlook shown was issued August 2000 and covers September-November 2000. Maps show seasonal mean surface air temperature and seasonal total precipitation probability anomalies. For example, for the temperature outlook, the contour that includes Great Salt Lake, UT shows a 5-10% probability anomaly for "warm" temperatures. Adjustment of base probabilities (33.3% for each tercile) results in a 38.3-43.3%, 33.3%, and 28.3-23.3% probability, respectively, that seasonal temperatures will fall within the "warm", "near normal", or "cool" tercile categories defined by regional conditions during 1961-1990.

Climate Outlook
September-November 2000
Temperature



Climate Outlook
September-November 2000
Precipitation



Release Date: August17, 2000

Figure 5.2. Example official seasonal climate outlook legend produced by the National Weather Service Climate Prediction Center.

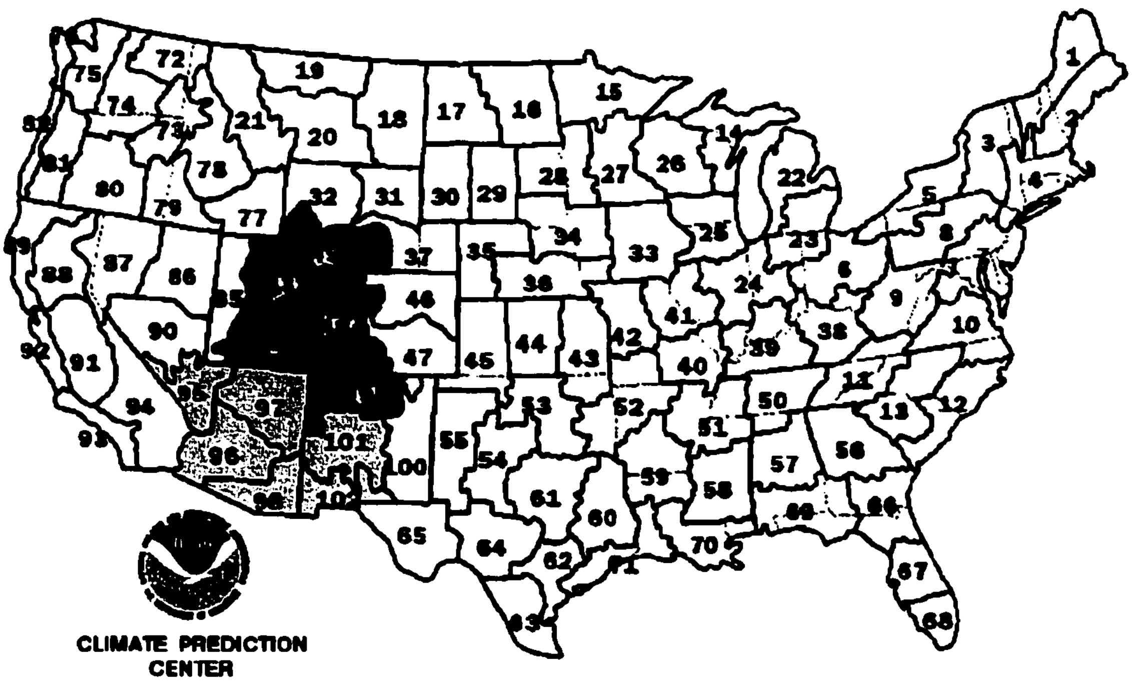
Precip	Temp	Probability anomaly as shown on map	Probability of occurrence for each class A	N	B	Most likely category
		40%-50%	73.3%-83.3%	23.3%-13.3%	3.3%	"Above"
		30%-40%	63.3%-73.3%	33.3-23.3%	3.3%	"Above"
		20%-30%	53.3-63.3%	33.3%	13.3%-3.3%	"Above"
		10%-20%	43.3-53.3%	33.3%	23.3%-13.3%	"Above"
		5%-10%	38.3-43.3%	33.3%	28.3%-23.3%	"Above"
		0%-5%	33.3-38.3%	33.3%	33.3%-28.3%	"Above"
		0%-5%	30.8%-33.3%	33.3%-38.3%	30.8%-33.3%	"Near Normal"
		5%-10%	28.3%-30.8%	38.3%-43.3%	28%3-30.8%	"Near Normal"
		0%-5%	33.3%-28.3%	33.3%	33.3%-28.3%	"Below"
		5%-10%	28.3%-23.3%	33.3%	38.3%-43.3%	"Below"
		10%-20%	23.3%-13.3%	33.3%	43.3%-53.3%	"Below"
		20%-30%	13.3%-3.3%	33.3%	53.3-63.3%	"Below"
		30%-40%	3.3%	33.3%-23.3%	63.3%-73.3%	"Below"
		40%-50%	3.3%	23.3%-13.3%	73.3%-83.3%	"Below"
		0%	33.3%	33.3%	33.3%	"Climatology"

precipitation probability anomaly maps to produce spatially-weighted probability anomalies for each of 102 regions within the conterminous U.S. The regions (Figure 5.3) are based on resampling the 344 climate divisions of NOAA's National Climate Data Center (NCDC). Forecast probabilities were obtained by adding map anomalies to the climatological probability of experiencing conditions within a given tercile (33.3%). The observation dataset, covering January 1995 - November 1999, consists of monthly average temperature and monthly total precipitation for each of the 102 regions based on spatially-weighted averages of NCDC climate division data. Tercile boundaries are based on Gaussian and gamma distributions fitted to the 1961-1990 observations for temperature and precipitation, respectively, with zero precipitation treated as censored data.

5.2.2 Measures of Forecast Performance

Distinction is made here between forecast quality, utility, and value. Quality concerns the correspondence between forecasts and subsequent observations, while utility addresses the role of forecasts in affecting decisions. Value accounts for the economic and incommensurate returns resulting from forecast use and depends on cost-loss functions that vary by user, with unique thresholds and risk tolerances. While some measures of quality can be used to rank forecasts by their utility as well (Krzysztofowicz, 1992), requisite assumptions that decisions be made optimally are often unmet. Only forecast quality is addressed herein.

Figure 5.3. Regions used in evaluating CPC seasonal climate outlooks. Upper and Lower Colorado River Basins are, respectively, indicated by green and yellow highlighted regions.



Myriad criteria exist for evaluating forecast quality (Wilks, 1995). Standard measures of performance (e.g., correlation, bias, root mean square error) commonly used for continuous variables (e.g., seasonal total precipitation) are unsuitable for the discrete events (e.g., falling within terciles) predicted by CPC climate forecasts. The values of various performance criteria are not, themselves, necessarily informative for decisionmakers (Hoffrage et al., 2000). Criteria differ in their upper and lower bounds, their desired value, and what change indicates improvement. A more consistent approach is used here, with criteria values compared to forecasts that decisionmakers would be using absent the CPC climate outlooks. "Climatology" forecasts (equal probabilities assigned to each tercile) are used here, reflecting their use in the CPC outlooks as the default forecast. The relative improvement provided by the CPC outlooks, compared to forecasting "climatology", is given as a skill score:

$$\text{Skill Score} = [1 - \text{score}_{\text{forecasts}}/\text{score}_{\text{climatology}}] \times 100 \qquad (1)$$

where $\text{score}_{\text{forecasts}}$ and $\text{score}_{\text{climatology}}$ are criteria values produced by the forecasts and climatology, respectively. For the sake of brevity, criteria used in the evaluation framework are presented here using descriptive terms only; Wilks (1995) provides a comprehensive presentation of the criteria using consistent terminology and equations.

A plethora of forecast performance criteria are based on contingency tables of categorical forecasts and event observations, and reflect whether forecasts 'hit' or 'miss' the condition subsequently observed (Wilks, 1995). The Heidke skill scores provided online with CPC forecasts are of this type. While each measure has its advantages, user concerns about specific climate conditions (i.e., terciles) are addressed in the simplest terms using the Probability of Detection (POD) and False Alarm Rate (FAR) (Wilks, 1995). For a given condition, the POD is the number of forecasts that ultimately prove correct, relative to the total number of times the condition actually occurs. For a given condition, the FAR is the number of forecasts that ultimately prove wrong, relative to the total number of times that forecast has been made. The POD considers all forecasts, while the FAR considers only forecasts for anomalous conditions (i.e., non-"climatology" forecasts).

Concepts associated with POD and FAR criteria can be extended beyond categorical forecasts to consider probabilistic forecasts, using the Brier Score (Brier, 1950; Wilks, 1995). It is computed like mean square error, with the error for a single forecast-observation pair being the difference between the forecast probability for a tercile category and the observed "probability" for that category (i.e., 0 if it did not occur and 1 if it did). Thus, if an event does not occur, forecasts indicating low probability for the event would not be heavily penalized compared to those indicating a high probability. Each tercile category receives its own Brier Score and accommodates the notion that decisionmakers often face differential consequences from opposing conditions (e.g., "wet" vs. "dry"). Only those forecasts with shifted tercile probabilities (non-"climatology" forecasts) are used in computations, consistent with the perspective of an informed user who understands that in CPC outlooks, "climatology" actually signifies the absence of any forecast (see Discussion section).

The Ranked Probability Score (RPS) is also computed like mean square error, but for each forecast-observation pair it compares cumulative forecast probabilities and multiple observation categories. Forecasts receive increasingly worse scores for assigning probabilities to categories increasingly distant from that observed (Epstein, 1969; Wilks, 1995). For example, if a season's observed total precipitation falls in the wet tercile, a forecast with probabilities of 28, 33, and 39% assigned to the dry, near-normal, and wet terciles, respectively, would not score as well as a forecast with respective probabilities of 3, 24, and 73%. Probabilities for all terciles, from all non-"climatology" forecasts, are used to compute a single RPS. As for the Brier score, "climatology" forecasts are considered non-forecasts and excluded.

The most comprehensive assessments of forecast performance are produced by examining various combinations of conditional and marginal distributions of forecasts and observations (Murphy and Winkler, 1987, 1992), as done by Murphy and Huang (1991) and Wilks (2000) for past and present generation CPC climate outlooks, respectively. Each distribution provides a different perspective on forecast performance and may be expressed or illustrated variably (e.g., Murphy et al., 1989; Murphy and Winkler, 1992). The distributions selected for the evaluation framework are those that can be related to the simpler criteria and user concerns. Examination of these distributions requires subdividing forecast probabilities and observations; tercile categories are used for the observations, while the probability intervals of the anomaly maps and legend (Figures 5.1 and 5.2) are used to subdivide the forecasts.

First, the conditional distribution of forecasts given observations and the marginal distribution of observations address questions about the ability of forecasts to detect specific conditions, analogous to the POD. Using the terminology of Murphy (1993), these distributions identify the ability of the forecast system to "discriminate" among climate events, whereby markedly different probability distributions are associated with different climate conditions. Discrimination is illustrated by plotting, for observations falling within a single tercile category, the relative frequency of probabilities assigned to "wet" and "dry" conditions, respectively, for each forecast probability interval. Second, the conditional distribution of observations given forecasts and the marginal distribution of forecasts address questions about the confidence that might be attributed to a forecast in-hand, analogous to the FAR. Following Murphy (1993), these distributions identify forecast "reliability", through correspondence between forecast probabilities and their associated relative frequencies of "correct" observations. Reliability is illustrated by plotting, for forecast probabilities assigned to a single climate condition (e.g., "wet"), the rate at which that condition actually occurs when forecasted using different probability intervals.

5.2.3 Selection of Forecasts for Evaluation

This section briefly presents decisionmaking contexts for three groups of prospective climate forecast users in the Southwest. Based on their planning horizons, seasons of sensitivity, and other concerns, several scenarios are developed for use in evaluating specific groups of CPC climate outlooks.

Water Management

Responsibilities of water management agencies in the Southwest are as diverse as the watersheds with which they are concerned, and encompass water delivery, reservoir regulation for water supply and flood control, and emergency flood response. Extensive discussion with a broad range of water management professionals (Carter et al., 2000; Pagano et al. 2002) identified periods especially important to decision makers concerned with seasonal water supplies originating primarily as mountain snowfall. Accumulation of snow throughout winter affects water supplies throughout the subsequent spring and summer. In the Southwest, the winter-snow/summer-flow relationship is particularly strong because late spring and early summer have little additional precipitation. Summer rains typically have little impact on useable water supplies in larger basins, but their transient local effects can be important to water managers (e.g., irrigation districts) that augment rainfall with contracted water deliveries or groundwater pumping.

Typically, in October, several water supply management agencies meet with the CBRFC to review potential winter and early spring conditions that will ultimately affect seasonal water supplies. For basins in the Southwest, the CPC climate outlooks relevant to this fall planning include forecasts issued in August, September, and October, covering December-May. Only those outlooks exclusively covering the decision period are considered here (i.e., DJF, JFM, FMA, MAM), to eliminate influence of conditions in other months; this set of outlooks comprises "Water Management Scenario-Fall" (WMS-F) and consists of 12 forecasts/year (Table 5.1). The second and third scenarios are consistent with official CBRFC water supply outlooks (Hartmann et al., 1999), typically

Table 5.1. Selected scenarios representing water management, ranching, and wildland fire management decisionmaking situations in the U.S. Southwest.

Decisionmaking Situation	Abbreviated Designation	When Forecasts Issued (months)	Season of Interest (months)
Water Management Scenario			
Fall	WMS-F	August-October	December-May
Winter, Upper Colorado	WMS-WUC	December-April	January-September
Winter, Lower Colorado	WMS-WLC	December-February	January-May
Spring	WMS-S	December-May	June-September
Cattle Ranching Scenario			
Summer	CRS-S	April-May	July-September
Winter	CRS-W	October-November	December-March
Fire Management Scenario			
Spring	FMW-S	January-March	April-July

issued semi-monthly January-May with varying temporal coverage that depends on basin seasonal flow characteristics. For the Upper Colorado River Basin (regions 48, 49, 83, 84, 99 in Figure 5.3), water supply forecasts are issued January-May and generally cover April-September, reflecting prolonged melting of extensive high-elevation snowpacks. The relevant climate forecasts comprising "WMS-Winter, Upper Colorado" (WMS-WUC) are those issued December-April and covering January-September (25 forecasts/year). The season of highest flows is much shorter in the Lower Colorado River Basin (regions 95-98, 101, 102), reflecting lower elevations, warmer temperatures, and less snowpack accumulation. "WMS-Winter, Lower Colorado" (WMS-WLC) includes climate forecasts issued during December-May and covering the January-May period; requiring outlooks to exclusively cover the decision period limits consideration to outlooks issued December-February (six forecasts/year). Finally, "WMS-Summer" (WMS-S) reflects the perspective of stakeholders relying on summer delivery of seasonal water supplies to augment rainfall, and includes forecasts issued January-May, covering June-September (10 forecasts/year).

Cattle Ranching

Ranching has important cultural, historical, ecological, and political significance in the Southwest (Sheridan, 1995; Conley et al., 1999). The vulnerability of ranching operations stems, in part, from dependence on rain-fed rangelands, although specific vulnerabilities also depend on the location and type of operations (e.g., cow-calf or steer operations). Ranchers' interests in climate forecasts primarily concern the predictability of grass production which, in turn, informs decisions to increase herd size to exploit a good grass season, purchase additional feed, or remove stock to prevent degradation of rangelands during drought. The specific season of interest depends on whether rangelands are most productive during winter (generally low-elevation range) or summer (high-elevation range). Ranching operations are highly diverse, making generalization unreliable. Two representative scenarios are considered herein. "Cattle Ranching Scenario-Summer" (CRS-S) (Table 5.1) encompasses forecasts made in April and May for July-September conditions (two forecasts/year), while "CRS-Winter" (CRS-W) uses forecasts made in October and November for December-March conditions (eight forecasts/year).

Wildland Fire Management

Wildland fires have historically been an important natural process throughout the Southwest, resulting from a reliably arid spring and early summer followed by lightning storms that occur prior to the summer monsoon (Swetnam and Betancourt, 1990). Increasingly, prescribed burn programs are used to prevent catastrophic wildfires by preemptively removing fuels under ideal field conditions. The specific seasons of interest to fire management agencies depend on the climate, elevation, and land cover type within their area of jurisdiction (ISPE, 2000). Low-elevation grasslands can be at high risk throughout a dry winter, while high-elevation forests generally have later fire seasons. Fire risk is also highly conditioned on prior climatic conditions, with the second dry winter after a wet winter, and a dry summer following a dry winter, being critical in the

Southwest. Regional fire managers from throughout the country submit their requests for seasonal resource needs (e.g., fire crews, equipment) to national headquarters in March, regardless of their actual fire season (ISPE, 2000). The scenario considered herein, "Fire Management Scenario-Spring" (FMS-S) (Table 5.1), encompasses forecasts issued January-March and covering April-July (six forecasts/year).

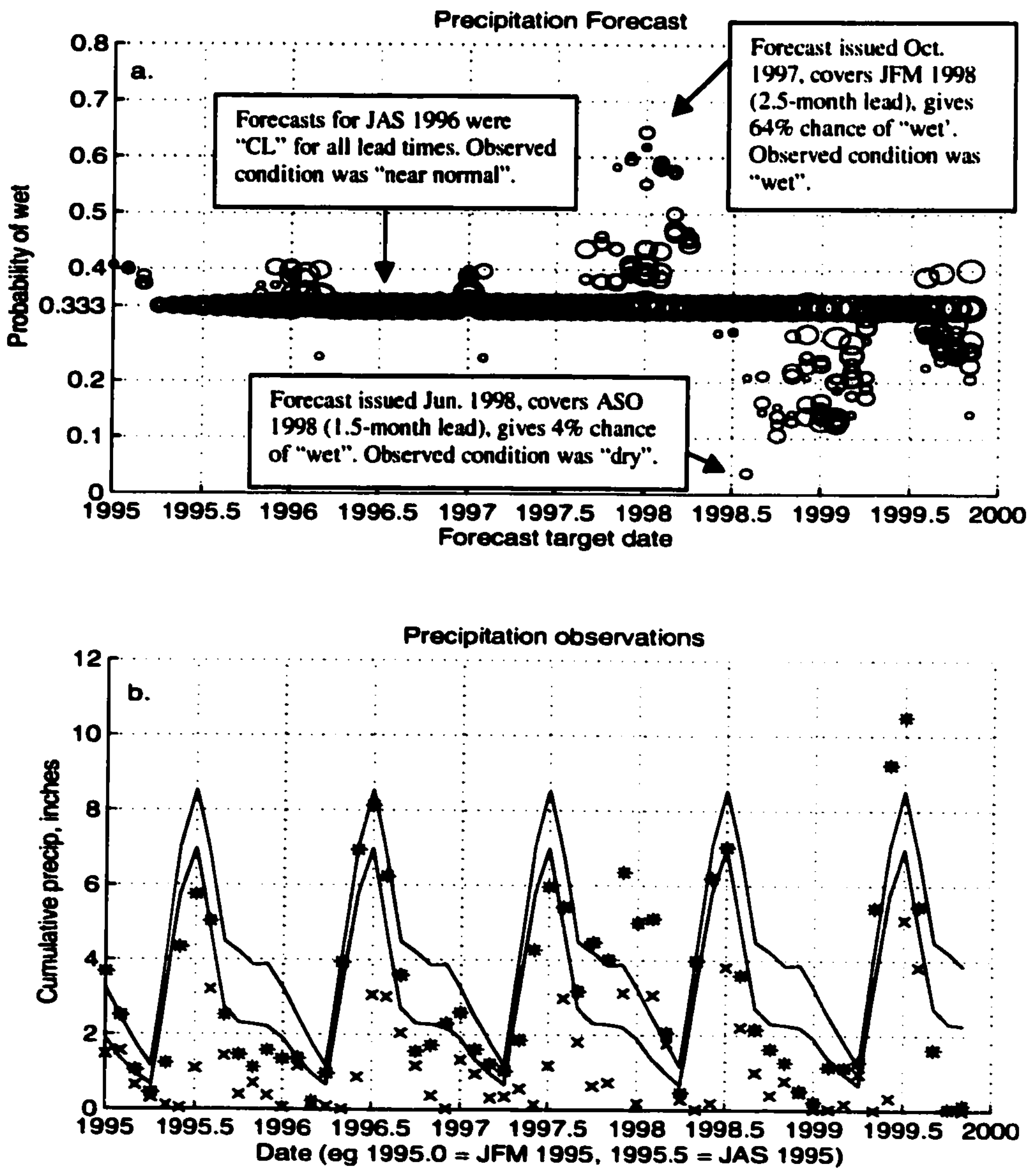
5.3 RESULTS

This section presents results of applying the forecast performance measures to CPC outlooks subsetted by the seasons and forecast lead times relevant to water managers, wildland fire managers, and cattle ranchers in the Southwest. Our evaluation framework is applied in its entirety to the water management sector, demonstrating how different criteria reveal different perspectives on forecast performance. Brevity limits presentation of results for wildland fire management and cattle ranching. However, comparison of results demonstrates.

General

Graphical representation of past forecasts and observations, as illustrated for southeastern Arizona (Figure 5.4), allows users to track forecasts as they have evolved over decreasing lead times and compare them to subsequent observations. CPC's standardized rules for shifting probabilities allow a complete forecast to be represented by a single probability for either the upper or lower tercile categories. In Figure 5.4a, the seasonal CPC precipitation forecasts are expressed as a probability of being in the upper

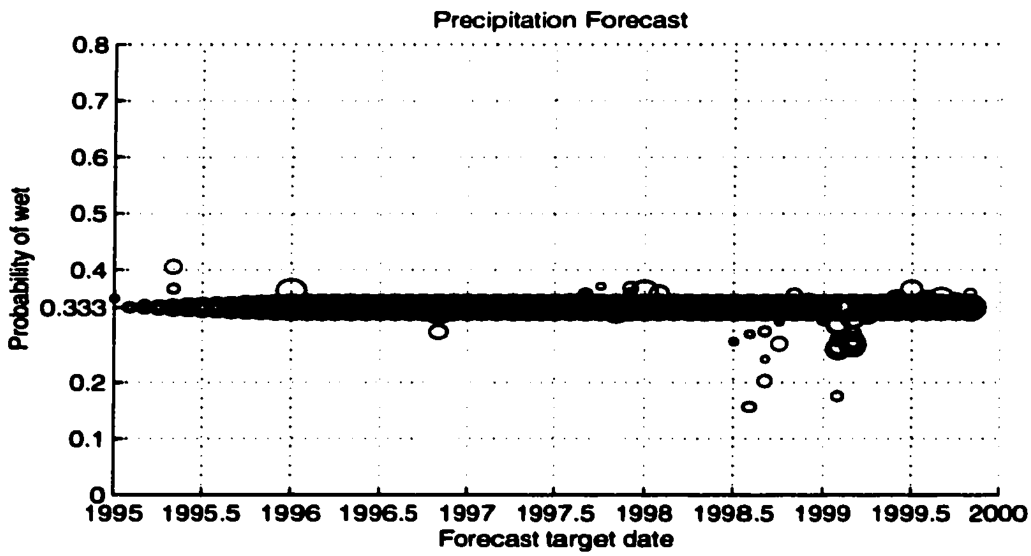
Figure 5.4. Graphical comparison of CPC seasonal precipitation outlooks and observed seasonal total precipitation for southeastern Arizona (region 98 in Figure 2). a) forecast probability of precipitation falling in the wet tercile; circle size indicates forecast lead time (0.5 to 12.5 months, smallest to largest). Color indicates observed category: wettest tercile (blue), middle tercile (green), driest tercile (red). b) observed precipitation; blue lines are 1961-1990 precipitation tercile boundaries, asterisks are 3-month observed total precipitation using same color scheme as part a), and x's are single month observed precipitation.



tercile (i.e., "wet"). While forecasts of an enhanced probability for conditions to fall within the middle tercile cannot be shown in Figure 5.4a, none have ever been made for seasonal precipitation. Observed monthly and 3-month seasonal total precipitation and the two tercile boundary lines are shown in Figure 5.4b.

Figure 5.4 indicates that non-climatology forecasts have been made frequently for southeastern Arizona. Further, those non-climatology forecasts have generally turned out to be consistent with observations, i.e., observations fell within the tercile category specified to have an enhanced probability of occurrence. Note that forecasts for a wet season can be correct, even though only a single month within the forecast period is actually wet (e.g., October-December 1997). On the other hand, (e.g., northeast Utah, Figure 5.5) non-climatology forecasts are relatively uncommon for regions in the Upper Colorado River Basin, despite high precipitation variability in the region.. Seasonal temperature forecasts for northwest Arizona and southern Nevada (Figure 5.6) have been consistent with the extended and extremely warm observations of 1995-1999. Tercile boundaries based on the region's entire historic record prior to the evaluation period (1895-1994) (not shown) are similar to those of 1961-1990, indicating how unusual temperatures have been.

Figure 5.5. Graphical comparison of CPC seasonal precipitation outlooks and observed seasonal total precipitation for northeastern Utah (region 83 in Figure 5.3). Legend same as Figure 5.4.



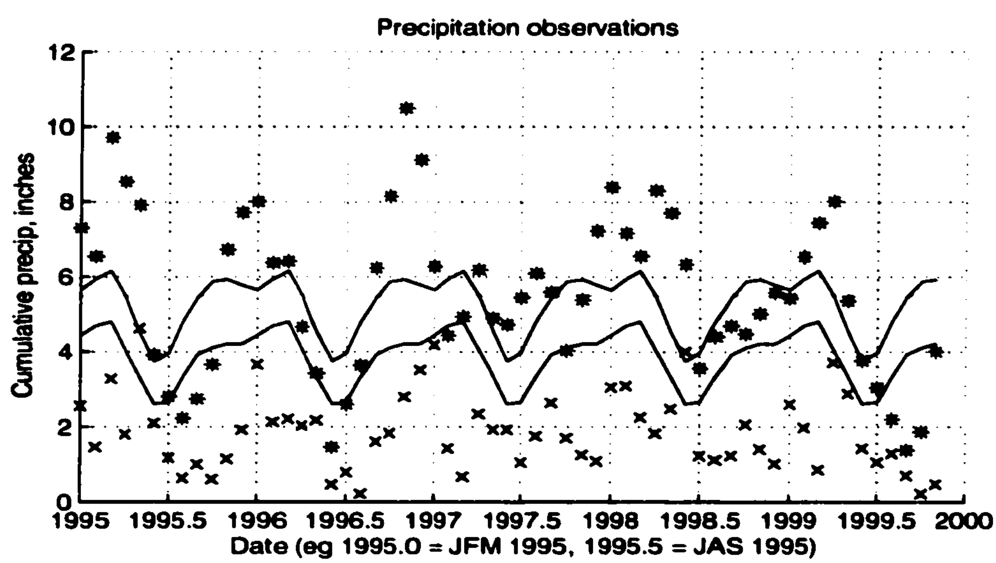
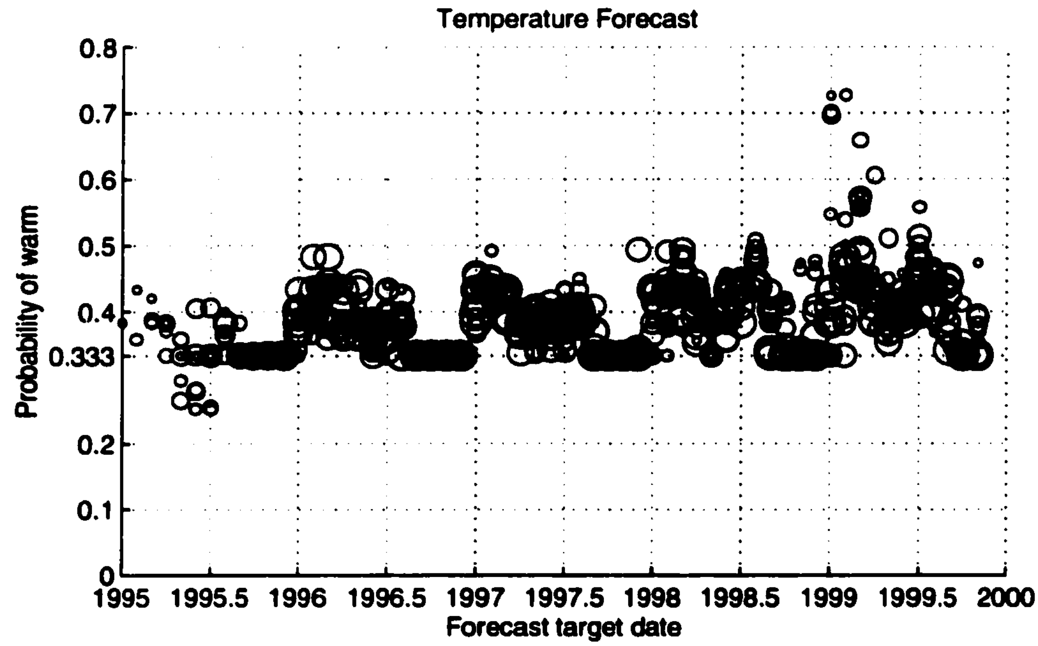
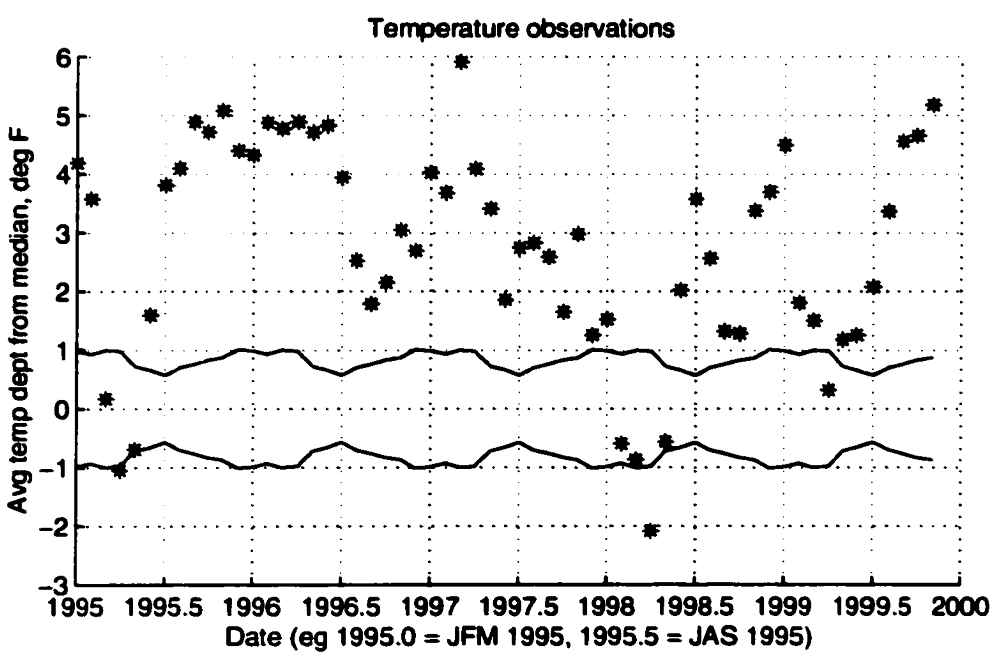


Figure 5.6. Graphical comparison of CPC seasonal temperature outlooks and observed seasonal average temperatures for northwestern Arizona and southern Nevada (region 95 in Figure 5.3). Legend same as Figure 5.4.





Water Management

Figure 5.7 shows POD and FAR, expressed as skill scores relative to climatological probabilities (i.e., 33.3% probability of occurrence of each tercile category), from the perspective of water managers that operate under the decision calendar of WMS-WLC (Table 5.1). CPC seasonal precipitation outlooks show skill for both wet and dry conditions for southeast Arizona; the specific forecasts used in the region's computations are illustrated in Figure 5.8. However, with the exception of FAR for the wettest tercile, performance of CPC seasonal precipitation outlooks for WMS-WLC is poor for much of the nation outside the Southwest. Figure 5.9 illustrates forecast skill for WMS-WLC based on the Brier score. For the Southwest, the seasonal climate outlooks are an improvement over using climatological probabilities for both "wet" and "dry" conditions, as expected from POD and FAR. Similarity between POD/FAR and Brier score results reflects that "wet" forecasts (generally limited to the winter of 1997-98) were made with relatively high probability and were consistent with subsequent observations (e.g., in Figure 5.8). Forecasts for the driest tercile, however, are shown more favorably using the Brier score rather than POD/FAR, because some forecasts were made with low probability and "dry" conditions did not occur.

Figure 5.10 shows RPSs computed for each of three water management scenarios (WMS-F, WMS-WLC, and WMS-S). Seasonal precipitation outlooks covering the winter, made with the shortest lead times (WMS-WLC), show RPS skill for most of the Pacific Coast, Southwest, and Gulf Coast regions (Figure 5.10b). Even with longer lead times (up to 6.5 months in WMS-F), the CPC forecasts show RPS skill for the Southwest

Figure 5.7. Probability of Detection (POD) and False Alarm Rate (FAR) for seasonal precipitation outlooks issued during December-February and covering January-May (Water Management Scenario – Winter, Lower Colorado). POD corresponding to a) driest and b) wettest tercile and FAR for c) driest and d) wettest tercile. Blue (red) circles indicate climate outlooks are better (worse) than chance (33.3%) forecasts; black circle indicates absence of non-climatology forecasts. Circle size indicates percent difference relative to potential shown by outer circle.

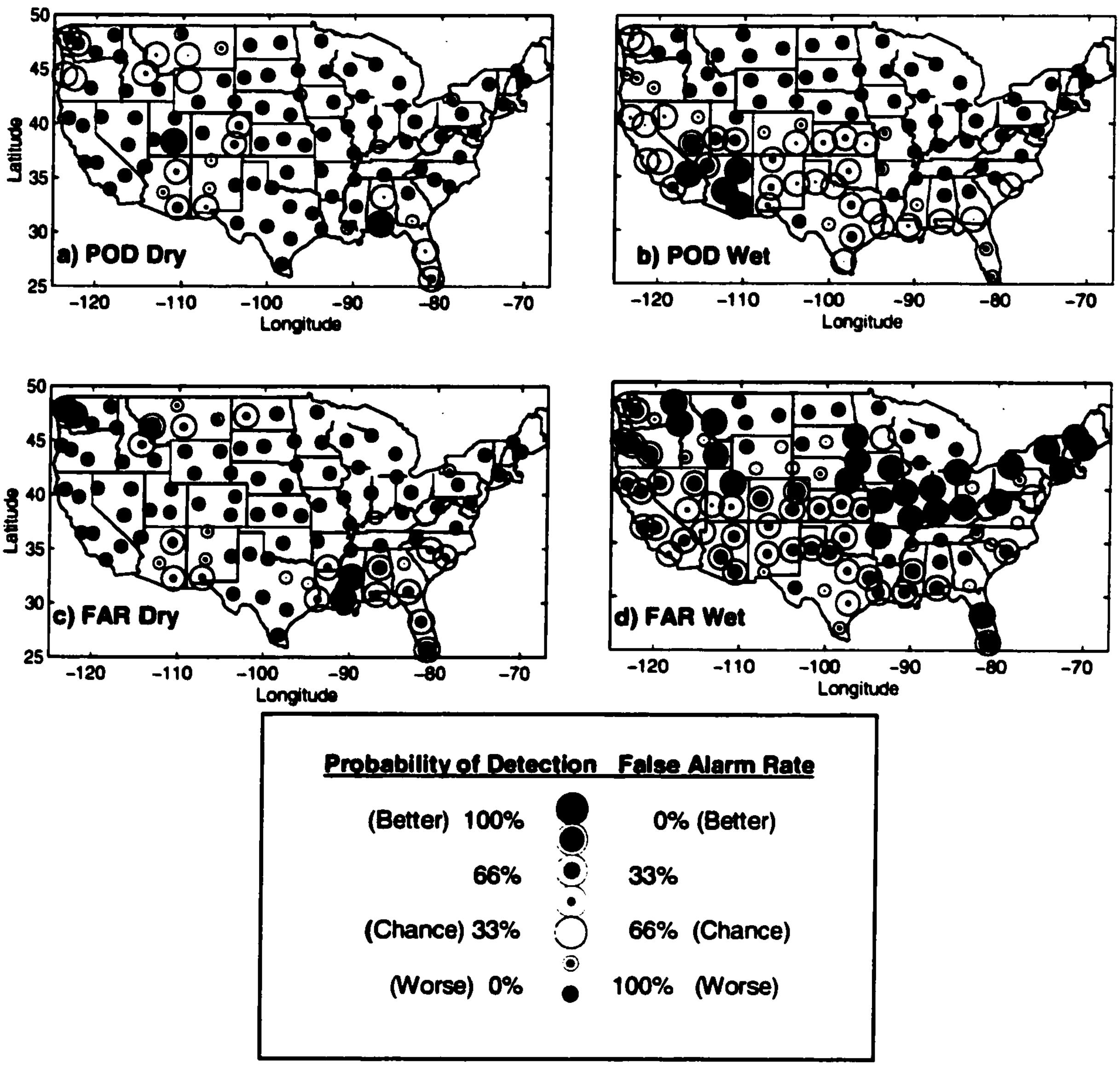


Figure 5.8. Graphical comparison of CPC seasonal precipitation outlooks and observed seasonal total precipitation for southeastern Arizona (region 98 in Figure 5.3) corresponding to outlooks issued during December-February and covering January-May (Water Management Scenario – Winter, Lower Colorado). Legend same as Figure 5.4a; see Figure 5.4b for corresponding observations.

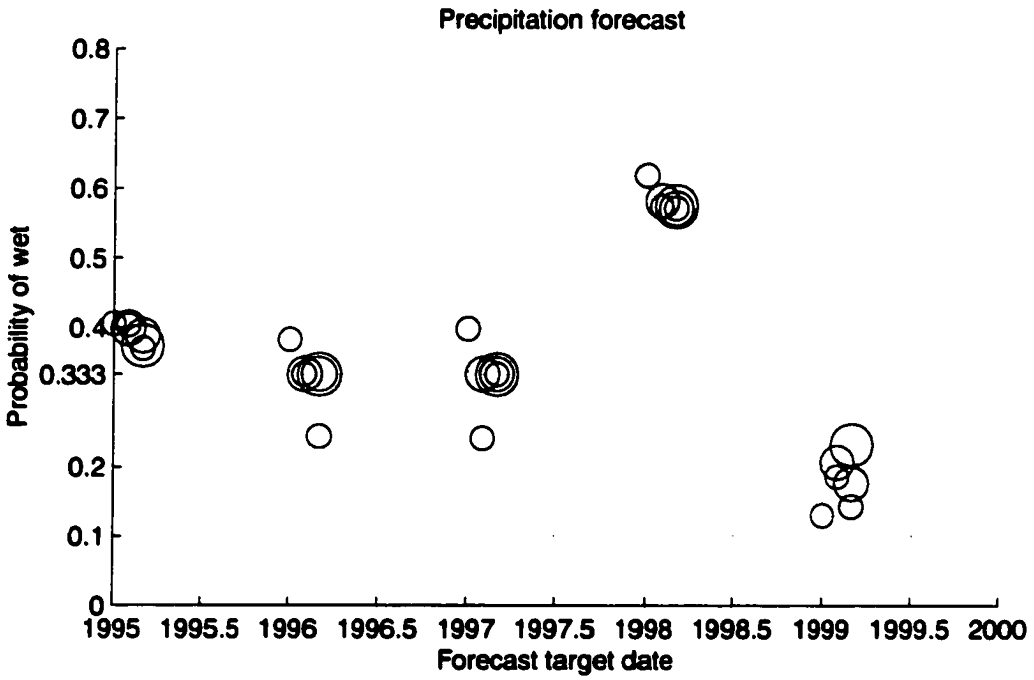


Figure 5.9. Skill scores for Brier Score for seasonal precipitation outlooks issued during December-February and covering January-May (Water Management Scenario – Winter, Lower Colorado). Only non-climatological forecasts are considered. a) wettest tercile, b) driest tercile. Blue (red) circles indicate climate outlooks are better (worse) than climatological probabilities (33.3% each tercile); circle size indicates percent difference relative to 50% change shown by outer circle.

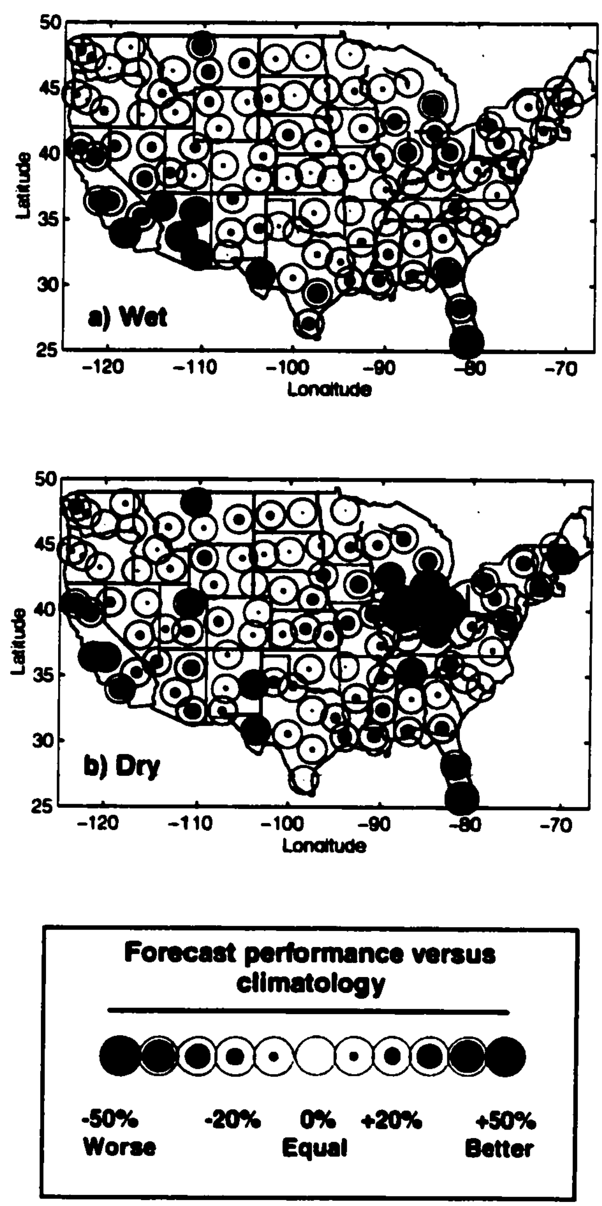
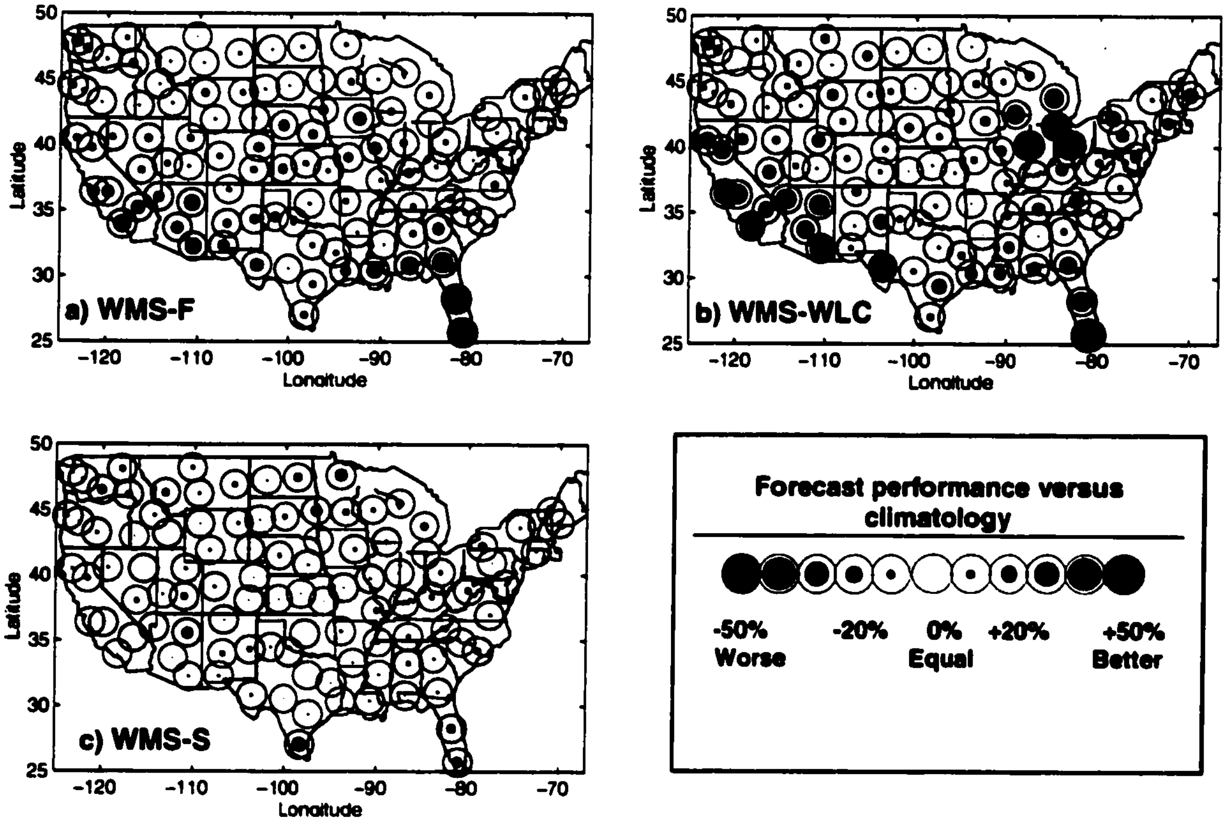


Figure 5.10. Skill scores for Ranked Probability Scores for seasonal precipitation outlooks for water management in the Southwest. Figures correspond to Water Management Scenarios a) Fall, b) Winter, Lower Colorado, and c) Summer. Legend same as Figure 5.9.



and Gulf Coast regions (Figure 5.10a). However, few regions show any RPS skill for WSM-S (Figure 5.10c) and several have never had non-"climatology" forecasts issued for this period.

Figure 5.11a-d shows discrimination diagrams for the Upper and Lower Colorado River Basins (WSM-WUC and WMS-WLC), along with frequency histograms of the observation categories (Figure 5.11e-f). In Figure 5.11a and 5.11b, perfect forecasts would show, for "wet" observations, that all forecasts had specified probabilities of 100% and 0% for "wet" and "dry" conditions to occur, respectively. While far from perfect, with the exception of "climatology" forecasts, Lower Colorado Basin forecasts show complete discrimination for "wet" observations (Figure 5.11a). "Dry" observations show some overlap in forecast probabilities specified for "wet" and "dry" conditions (Figure 5.11c), but not nearly so much as for the Upper Colorado Basin. There, the distributions of forecast probabilities for "wet" and "dry" conditions vary little between "wet" and "dry" observations, and are dominated by "climatology" statements (Figure 5.11b and 5.11d).

Figure 5.12a-b shows reliability diagrams for the Upper and Lower Colorado River Basins (WSM-WUC and WMS-WLC). Perfect specification of forecast confidence would result in perfect alignment of forecast probabilities and observational frequencies (i.e., all points in Figure 5.12a-b falling along the 45° line). For the Lower Basin, for forecasts of both "wet" and "dry" conditions (the blue and red lines in Figure 5.12a, respectively), the frequency of "wet" and "dry" observations generally increases with the forecast probability. Forecast confidence has been understated, especially for forecasts of

Figure 5.11. Discrimination diagrams (a-d) and observation histograms (e,f) for seasonal precipitation outlooks relevant to water supply management: a,c,e) lower Colorado Basin, issued December-February and covering January-May (Water Management Scenario – Winter, Lower Colorado), and b,d,f) upper Colorado Basin, issued December-April and covering January-September (Water Management Scenario – Winter, Upper Colorado). Discrimination diagrams conditioned on observations for: a,b) wet and c,d) dry terciles. Blue (red) circles show relative frequency of forecasts issued with indicated probability for wet (dry) conditions.

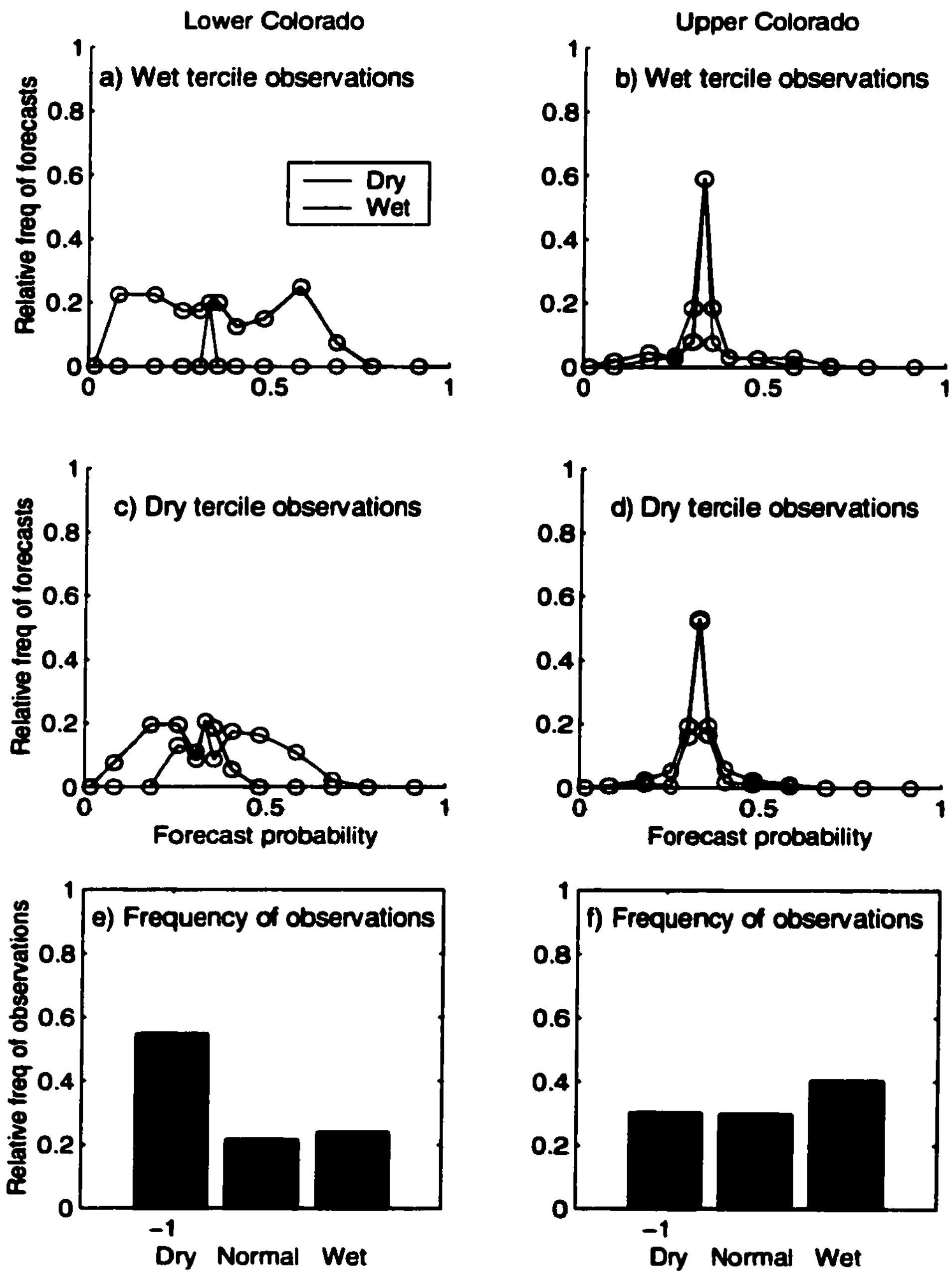
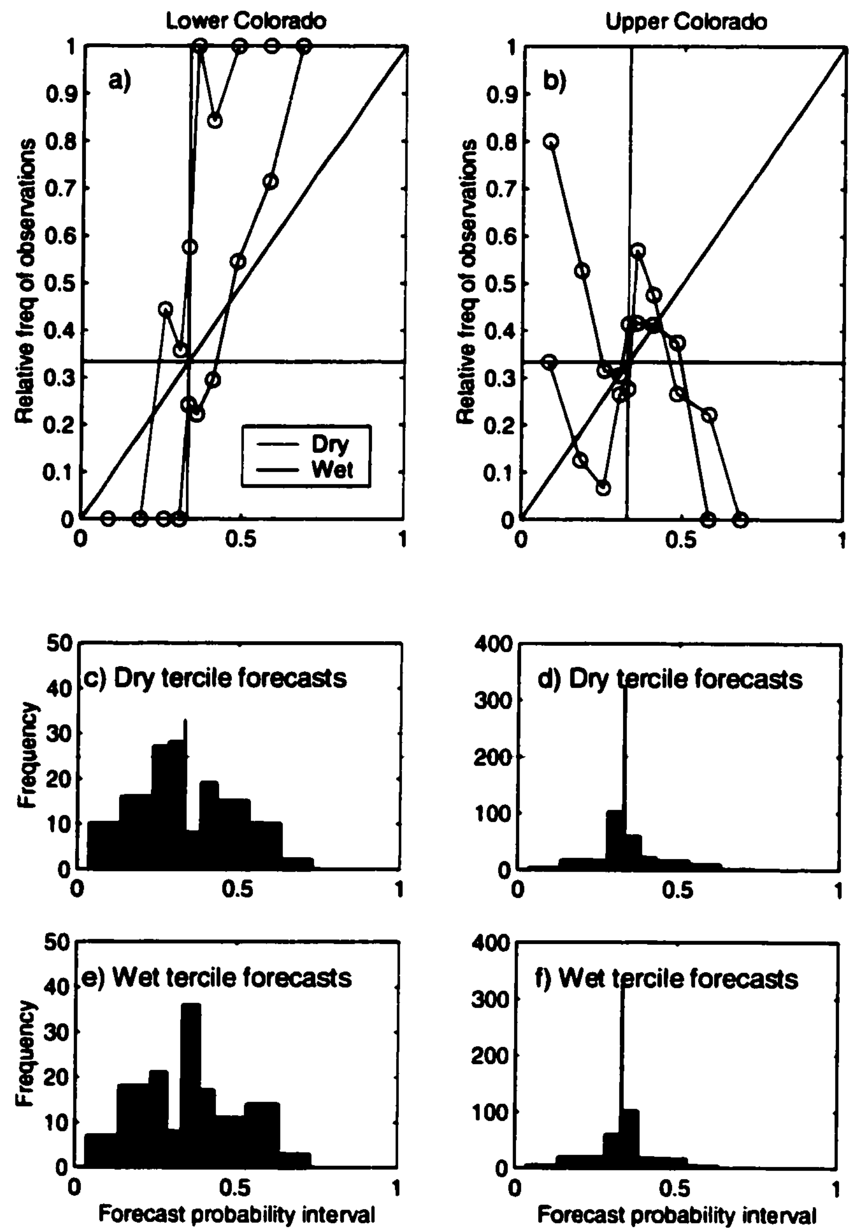


Figure 5.12. Reliability diagrams (a,b) and forecast probability histograms (c-f) for seasonal precipitation outlooks relevant to water supply management: a,c,e) lower Colorado Basin, issued December-February and covering January-May (Water Management Scenario – Winter, Lower Colorado), and b,d,f) upper Colorado Basin, issued December-April and covering January-September (Water Management Scenario – Winter, Upper Colorado). In reliability diagrams, blue (red) circles show fraction of wet (dry) observations occurring when forecast with the indicated probability. Black lines reference climatological forecast probability (vertical) and observation frequency (horizontal), and perfect forecast reliability (45 degree line). Histograms conditioned on forecasts for: c,d) dry and e,f) wet terciles.



"dry" conditions. In contrast, Upper Basin forecasts (Figure 5.12b) show poor reliability, especially for the most extreme forecast probabilities. Frequency histograms of the probability intervals used to forecast "wet" and "dry" conditions (Figure 5.12c-f) show the paucity of non-"climatology" forecasts for the Upper Basin relative to the Lower Basin.

Wildland Fire Management

Using Brier Scores, Figure 5.13 assesses seasonal temperature and precipitation outlooks from the perspective of wildland fire managers (FMS-S). For a few areas within the Southwest, there is some skill with regard to "cool" temperatures that may be useful for planning seasonal prescribed burn opportunities. However, precipitation and temperature forecasts covering April-July are generally poor, even for the relatively short lead times considered.

Cattle Ranching

Using RPS, Figure 5.14 assesses seasonal temperature and precipitation outlooks from the perspective of cattle ranchers (CRS-S and CRS-W). Figure 5.14a shows that even with the relatively short lead times used by ranchers for summer operations (CRS-S), CPC precipitation outlooks for the Southwest have provided no information (i.e., only "climatology" designations). Some temperature forecasts do show skill, however (Figure 5.14c). CPC outlooks for winter conditions (CRS-W) show RPS skill for both

Figure 5.13. Skill scores for Brier Score for seasonal precipitation and temperature outlooks issued during January-March and covering April-July (Fire Management Scenario - Spring). Only non-climatological forecasts are considered. Figures show precipitation: a) wettest and b) driest, and temperature: c) warmest and d) coolest terciles. Legend same as Figure 5.9.

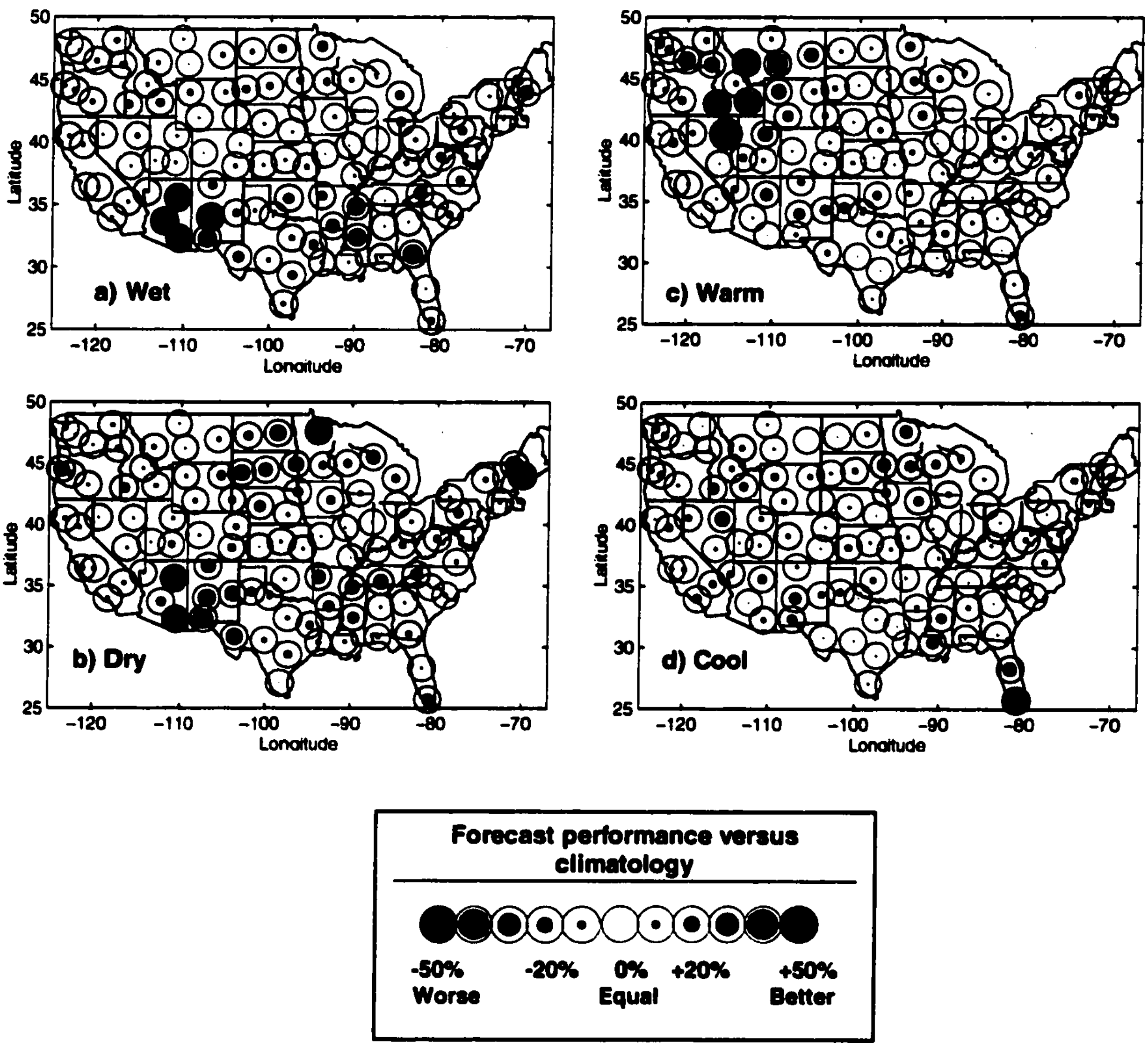
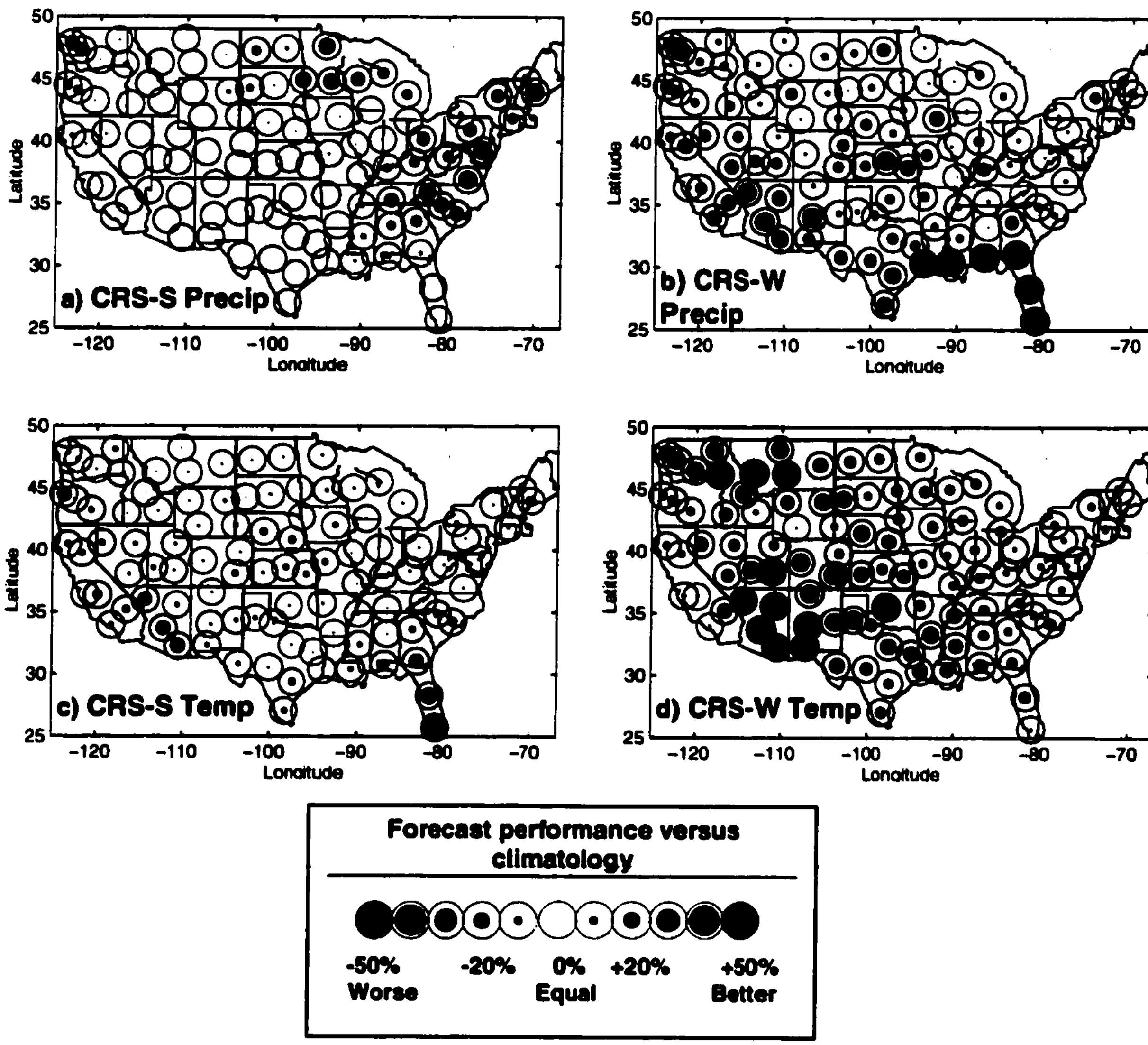


Figure 5.14. Skill scores for Ranked Probability Scores for seasonal precipitation and temperature outlooks for cattle ranching in the Southwest. Figures correspond to Cattle Ranching Scenario – Summer : a) precipitation and c) temperature, and Winter: b) precipitation and d) temperature. Legend same as Figure 5.9.



precipitation and temperature (Figure 5.14b and 5.14d, respectively), with the Southwest and Gulf Coast showing generally the best combined performance.

5.4 DISCUSSION

5.4.1 Forecast Evaluation Issues

While CPC climate outlooks have been evaluated repeatedly throughout the years, with few exceptions (e.g., Mjelde et al. 1983; Lehman 1987) reviews of earlier products have been framed for researchers and forecasters rather than users, and few distinguish among regions within the Southwest. Frequently updated evaluations, easily accessible to users, accompany CPC climate forecasts online. However, they consist of Heidke skill scores computed for each season for the entire conterminous U.S., without regional breakdowns. Spatially distributed skill assessments are similarly available online for some individual forecasting techniques, but are insufficient to evaluate official outlooks derived by temporally variable subjective combination of many individual techniques and forecaster judgment. Wilks' (2000) assessment of current generation outlooks, while extensive, provided only national and large regional perspectives (e.g., the Upper and Lower Colorado River Basins were considered part of the Pacific Northwest and Southern regions, respectively). Further, Wilks noted his results were admittedly more useful to forecasters than users, not only due to coarse spatial scale, but to the complexity of evaluation products as well.

Long-term forecasts pose special difficulties for quantitative evaluation. First, climate outlooks concern only average temperatures and total precipitation over an entire forecast period, not within it. They say nothing about daily, weekly, or even monthly extremes within a 3-month forecast period, or whether precipitation will occur as many small, or a few large, events. However, in semi-arid regions seasonal precipitation can be defined by a single event. For example, the 1997-98 El Niño autumn climate was extremely wet in southwest Arizona due to the storm track of Hurricane Nora (Pagano et al., 1999). Second, limited sample sizes compromise even the most mathematically rigorous analyses. Spatial and temporal autocorrelation reduce effective sample sizes further, and forecast technology changes faster than sufficient data can accumulate.

What constitutes a perfect forecast? Perfect foreknowledge would allow forecasts to be made correctly, with 100% certainty (a probability of 100% in Figure 5.1 for any indicated condition, with no region classified as "climatology"). Although the climate system's chaotic nature (Hansen et al., 1997) precludes reasonable expectations of perfect predictions, forecast probabilities reflect more than diverse possibilities of system states. They also reflect the subjective assignment of confidence or certainty to the forecast based on the skill of predictive technologies, including forecaster expertise. In this case, perfect assignment of forecast probabilities would produce complete correspondence, in the aggregate, between assigned probabilities and the rate of occurrence of indicated conditions. Thus, for example, over many forecasts, precipitation would actually fall within the upper tercile in 60% of the cases for which forecasts indicated 60% probability of having a 'wet' season.

To metaphrase Tolstoy (1917), while all perfect forecasts resemble one another, imperfect forecasts are imperfect in their own unique ways. Murphy (1993) describes nine complementary ways in which forecasts can be imperfect. Many other measures have been used or proposed (Ward and Folland, 1991; Krzysztofowicz, 1992; Winkler, 1994; Wilks, 1995; Mason and Graham, 1999) as well as alternative means for communicating performance statistics (Hoffrage et al., 2000). The diversity of forecast performance measures, with each possessing different characteristics and interpretations, presents real potential for confusing forecast users. Which aspects of quality are most important to users depend on the specifics of their decisionmaking situations. Further, acceptable tradeoffs between contextual specificity (e.g., region, lead time, season) and sufficient sampling differ by users' risk tolerance and are not reliably determined without their input.

Earlier generations of CPC seasonal climate outlooks consisted of categorical forecasts (i.e., without associated probabilities and thus with implied 100% probability of occurrence), and evaluations assessed correspondence between forecasted and observed events (e.g., Bettge et al., 1981). However, all criteria based on contingency tables, including POD and FAR, unfairly neglect the probabilistic character of current generation forecasts. Such simple criteria are not advocated here as being the right standards for assessing forecast performance, but they are perhaps the easiest for users to understand because they simply reflect counts of forecasted and observed conditions that users can easily track. Further, POD and FAR can directly address specific questions users have about the forecasts, while allowing distinction among important climate conditions.

Assessments of current generation outlooks are complicated by their probabilistic nature; the forecasts are never "wrong" because they always reserve at least a 3.3%

probability that conditions will fall within a tercile category. Evaluations using the Brier score logically build upon POD/FAR evaluations, because they still allow users to focus on specific climate conditions (e.g., "wet" or "dry"), but also incorporate forecast probabilities. Comparison of Brier score and POD/FAR results makes clear the potential for users to be disappointed in forecast performance, and ultimately attribute lower credibility to the outlooks than is deserved, when probabilities are converted to categorical forecasts. One drawback of the Brier score is that it neglects the distribution of forecast probabilities outside the climate category of interest (e.g., upper tercile) when, clearly, it's preferable to place most of that distribution in an adjacent category (i.e., central tercile) rather than a distant category (i.e., lower tercile). RPS evaluations logically build upon Brier score evaluations, because they are computed similarly but incorporate the entire forecast probability distribution. However, the ability to separately evaluate forecasts for specific climate conditions is lost, limiting its usefulness to situations where forecast consequences are similar among all climate conditions.

The advantage of evaluating conditional distributions is the ability to identify specific situations whereby forecasts perform particularly well or poorly. Obtaining sufficient sample sizes for each prospective situation is problematic, however, requiring pragmatic grouping of forecast-observation pairs across multiple regions, lead times, seasons, and distribution categories. Further, the complexity of the evaluation products probably limits their interpretation by non-specialists. Within the Southwest, regional water management agencies are likely to be among the few decisionmakers with sufficient staff expertise, operational flexibility, and regional purview to make use of conditional distribution evaluations.

5.4.2 Forecast Performance Implications

For some situations, CPC seasonal climate outlooks have shown greater predictive skill than forecasts based simply on 1961-1990 climatology. Although results may be similar for users with similar planning horizons and seasons of operation (e.g., WMS-S and CRS-S), targeted analyses allow users to focus on results not clouded by forecasts they consider irrelevant. By using results that reflect user perspectives, interactions between decisionmakers and forecasters can now begin to determine essential forecast attributes; requisite performance thresholds; relationships among forecast quality, utility, and value; and the potential utility and value of forecast improvements. The demonstrated forecast skill, or lack thereof, provides a basis for exploring, with users, forecast performance implications from a context of experience rather than conjecture. The brief examples discussed here illustrate how forecast quality can have implications for prioritizing scientific efforts, realizing competitive advantages, adjusting management processes, and changing climate forecasting efforts.

The implications of forecast performance are different for water managers of the Upper versus Lower Colorado River Basins. Poor climate forecast skill within the Upper Basin, where upper elevation snowpacks are the source for almost all streamflows, reinforces the vital importance of high quality estimates of existing snowpack conditions (e.g., coverage, water content). Within the Lower Basin, snowpack is less extensive and reliable (nearly absent some years), making flow forecasts more dependent on rainfall and thus less predictable (Shafer and Huddleston, 1985). However, climate forecast skill for this region during the winter and spring offers potential for improving Lower Basin streamflow predictions.

Within the Southwest, climate forecasts perform better from the perspective of cattle ranchers making use of winter range, compared to those using summer range. *Inter alia*, the greater climate predictability provides competitive advantages, if the ranchers have financial and operational flexibility to exploit them. Further, anything ranchers can do to shift operational risks from summer to winter would improve their competitive situation.

The poor performance of climate outlooks from the perspective of wildland fire management agencies suggests real potential for disutility if the forecasts are incorporated into decisions without extreme care. A supplementary analysis explored the idea that requiring fire managers to submit budget, equipment, and personnel requests in March limits the potential usefulness of the climate outlooks. Forecasts issued at other times were assessed to determine presence of any skill. The 102 regions of Figure 5.3 were combined into 10 regions representing current wildland fire management divisions (*www.nifc.gov/fireinfo/geomap.html*). All 4-month seasons (two forecasts) issued with 0.5-month lead time were evaluated for each of the 10 divisions, and for 10 adjusted divisions that reflect more cohesive climate and land cover conditions. Results (not shown) indicated that only those regions for which winter fire risks are important (e.g., southern California) could possibly benefit from seasonal climate outlook skill. However, to the extent that other regions have fire risks affected by winter conditions (e.g., during some years in the Southwest), forecast skill at even longer lead times (e.g., WMS-F, CRS-W) may prove useful, although not under current resource request schedules.

Evaluations show that seasonal average temperatures have been consistently within the upper terciles of both climatological (1961-1990) and historical (period of record) records, reinforcing the argument that 1961-1990 climatology is a poor base forecast. An extended persistence forecast (e.g., 5-year optimal climate normal) may be more appropriate than a 30-year climatology with a 10-year lag. Finally, seasonal temperature forecast skill may be good enough that forecasters should now aim for a target smaller than terciles (e.g, quartiles), offering increased forecast utility as long as performance quality is maintained. However, modified temperature forecasts would require separate temperature and precipitation legends (showing four and three event categories, respectively).

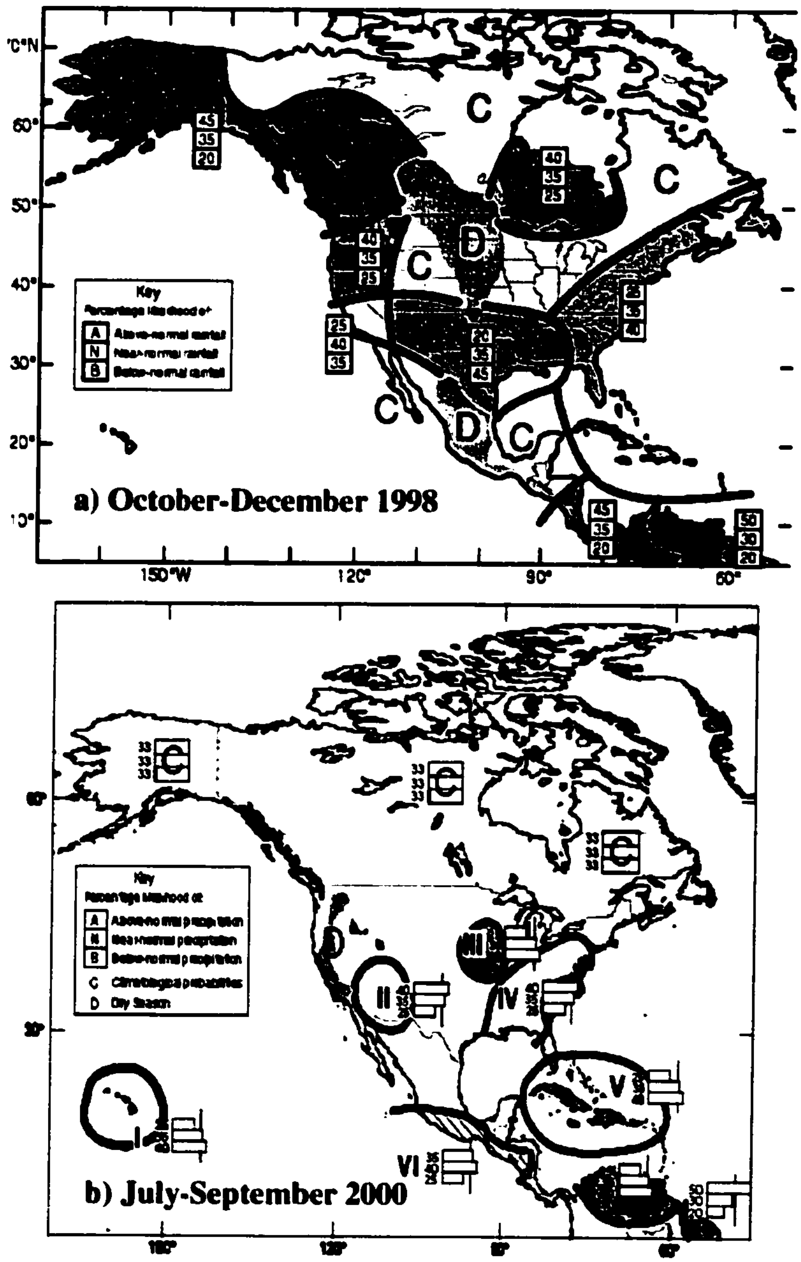
5.4.3 Forecast Communication Issues

Qualitative aspects of climate forecast products can be as important as any quantitative attribute in affecting how users interpret, apply, and ultimately judge them (Nicholls, 1999). Discussions with many users indicate that even those with technical backgrounds are consistently misinterpreting CPC outlook content (Pagano et al., 2001). Interaction with users through surveys, structured discussions, or other innovative means (National Research Council, 1999b) should be used to comprehensively assess forecast qualities and influence creation of products that foster easy, accurate, and reliable interpretation. Three issues are presented here that deserve further attention, jointly, by forecasters, social scientists, and forecast users.

First, although CPC outlook maps illustrate temperature and precipitation probability anomalies, they are often interpreted as quantities. Map contours often form a "bull's-eye" (e.g., the area over southwest Arizona in Figure 5.1), identifying regions for which stronger statements are being made about the likelihood of indicated conditions. However, these contours are often interpreted as meaning the center region is expected to have more extreme conditions than surrounding areas. Although lower in spatial resolution, experimental climate forecasts made by the IRI (Figure 5.15) do not use contours, offering more reliable interpretation.

Second, anomalies are relative only to a limited historical period (1961-1990). Recent conditions are not referenced, although they are most fresh in decisionmakers' minds. For example, Changnon et al. (1988) found that agribusiness decisionmakers in the Midwest focus on conditions over the prior 3-6 years. Decisionmakers may relate to climate forecasts better if they are compared to recent conditions. CPC's experimental probability of exceedance graphs (Barnston et al., 2000) show recent conditions (10 years for temperature, 15 years for precipitation), although the graphs pose their own interpretive difficulties. Problems of ignoring the recent past in official forecast products will be obviated, for a few years, after the climatological period is updated to 1971-2000 (June 2001). However, that aggravates another problem, which is ignoring periods further in the past. For some parts of the U.S., periods separated by nearly a century have more in common than with intervening regimes (e.g., Quinn, 1981). With understanding of

Figure 5.15. Seasonal climate outlooks produced by the International Research Institute for Climate Prediction: a) older format, forecast produced October 1998 and covering October-December 1998, and b) newer format, forecast produced June 2000 and covering July-September 2000.



decadal- and centennial-scale regimes improving, neglecting to communicate the longer historical record seems ill advised. For example, mass immigration to the Southwest over the past decade means many residents have lived in the region for only a few years and have experienced only the recent past. If a longer perspective is not clearly communicated, newcomers will have little appreciation of the range of potential variability.

Third, designating areas with "climatology" is misleading if not incorrect. CPC climate outlooks often have some areas, and sometimes the entire conterminous U.S., labeled "climatology". It does not indicate that conditions are likely to be "normal". Rather, the forecast legend (Figure 5.2) says "climatology" indicates equal probability of occurrence for each tercile condition. However, CPC protocols require "climatology" to be used when forecast techniques lack skill for a particular combination of region, forecast period, and lead time, or when individual forecast techniques produce conflicting guidance that cannot be resolved through forecaster expertise. CPC climate outlooks made with lower quality graphics (Hartmann et al., 1999) explicitly indicate that "climatology" means there is insufficient skill upon which to base a forecast, although they also provide an equal probability interpretation. Comparison with observations shows that "climatology" forecasts are not unbiased predictors of uniformly distributed conditions. Considering all regions and lead times, 52% and 21% of the "climatology" forecasts for temperature corresponded to observations in the warmest and coolest terciles, respectively, while 42% and 28% of "climatology" forecasts for precipitation corresponded to observations in the wettest and driest terciles.

Climate outlooks, especially those with long lead times, often are based largely on optimal climate normals (T. Barnston, 1999, CPC, personal communication), with the optimal averaging period being the past 10 years for temperature and the past 15 years for precipitation. Using the official legend's definition, a "climatology" forecast is equivalent to a 30-year optimal climate normal with a 10-year lag. Because they have different implications for decisionmaking, a designation of "complete forecast uncertainty" or "no forecast confidence" is more appropriate than an equal-probability forecast. Earlier generations of NWS seasonal climate forecasts included an "indeterminate" classification (Bettge et al., 1981). Lacking an explicit forecast from the national product, users may then decide to use other forecast approaches that have regional merit. For example, Lamb and Changnon (1981) found a 5-year normal to work best overall in predicting seasonal precipitation and temperatures in Illinois, although when predictions were in error, the errors were larger than when based on 10- or 15-year periods.

5.5 CONCLUSIONS

Frequently updated forecast evaluations, using multiple criteria, should be available to potential users of seasonal climate outlooks. The evaluation framework presented here provides several criteria that accommodate variation in users' interpretive abilities. The framework offers tradeoffs between different levels of informativeness and understandability, and enables users to increase the sophistication of their understanding about climate forecasts, credibility, and implications for decisionmaking.

Graphical representation of recent forecasts and observations enables intuitive identification of multiple performance attributes. Forecast characteristics that stand out graphically include the seasonality of forecast confidence, tendencies to use only "climatology" (i.e., to not provide a forecast), and consistency in the direction of predicted anomalies as forecast lead times diminish. The extremity or normalcy of recent conditions can also be clearly identified and placed in historical context. Finally, specific forecasts can be directly compared to their associated observations. Although probabilistic forecasts are more appropriately judged in the aggregate rather than individually, displaying a time series of all forecasts should help users visualize aggregate performance. Products such as Figures 5.4-5.6 and 5.8 represent a starting point for determining, through interaction with users, effective formats.

Forecast performance criteria based on 'hitting' or 'missing' associated observations (e.g., POD and FAR) offer users conceptually easy entry into discussions about forecast quality. They are relatively simple to compute and communicate and can be related to specific user concerns. However, they unfairly penalize the CPC forecasts by neglecting differences between weak and strong confidence statements. The Brier score offers potential for extending user understanding of forecast quality by considering the strength of probability statements. However, it still allows users to target specific conditions that can have differential consequences (e.g., wet or dry terciles). The RPS further extends notions of forecast quality through consideration of multiple observation categories and cumulative forecast probabilities. However, it is more appropriate for users interested in the full range of conditions. The common graphical format used to present results for these evaluation criteria (e.g., Figures 5.7, 5.9), while simplistic, is relatively easy to understand, illustrates spatial coherence of forecast performance, and allows comparison among regions and criteria. Conditional distributions of forecasts and observations provide the most comprehensive evaluations available to users. However, their sensitivity to small sample sizes and the complexity of interpretation may limit usefulness to all but regional entities staffed with specialists (e.g., water management agencies responsible for large river basins).

Forecast evaluations should focus on specific regions, seasons, and lead times of interest to different decisionmakers. CPC seasonal climate outlooks clearly perform better for some users than others. From the perspective of water managers in the Southwest, winter precipitation outlooks made during fall and winter are better than climatology forecasts according to all criteria. Winter and spring forecasts of summer precipitation lack skill, and in many areas have provided no guidance at all, indicating only "climatology". Compared to the Upper Colorado River Basin, not only does the Lower Basin benefit from greater storage capacity (Harding et al., 1995), but from greater climate predictability as well. CPC climate outlooks lack skill when assessed under current decisionmaking schedules used by wildland fire management agencies. However, if schedules are flexible, forecast skill may prove useful where fire risks are affected by winter conditions (e.g., southern California, the Southwest). Cattle ranchers using winter range have greater competitive advantage over those using summer range, due to greater predictability of both seasonal precipitation and temperature.

Review of the CPC seasonal climate outlooks identified several product format limitations. No singular advantage was found for any of several formats in use. However, concentric contours used in CPC outlooks pose interpretation problems not found in alternative products. The most egregious problem is use of the "climatology" designation, causing misinterpretations throughout research, applications, and user communities. The "climatology" designation should be replaced with a more explicit statement of no forecast confidence. Worth considering is revival of the phrase "interdeterminate", which was used in NWS seasonal climate outlooks issued prior to mid-1982. More generally, forecast product development should involve expertise in visualization and communication, with field testing by a variety of potential users.

CHAPTER SIX

CONCLUSIONS

6.1 SUMMARY

The primary objective of this research was to identify, develop, and implement and coordinated stakeholder driven research agenda concerning hydroclimatic forecasts, as part of the CLIMAS project. The research agenda was based on two additional research efforts. First, direct interaction was used to establish an understanding of selected stakeholder groups with interests related to hydroclimatic variability in the U.S. Southwest, in terms of their use of hydroclimatic information and forecasts. Second, the current state of hydroclimatic forecasting was reviewed, including a survey of weather, climate, and hydrologic forecasts available to stakeholders in the Southwest. From these foundations, a scientific research agenda was developed that reflects common concerns and interests of diverse stakeholders, as well as opportunities for scientific advancements, particularly regarding hydrologic predictability. Within the research agenda, consistent assessment of different forecast products in ways that have meaning for diverse stakeholders was enabled through the development of a forecast assessment framework encompassing qualitative, graphical, and quantitative evaluation.

6.2 STAKEHOLDER USE OF HYDROCLIMATIC INFORMATION AND FORECASTS

Generally, individuals with training in hydroclimatology and agencies with internal expertise had the best understanding of hydroclimatic processes. However, stakeholder perspectives about hydroclimatic processes and variability differ as much within a single sector as across different groups. Uniformly across stakeholder groups, individuals were often uninformed or had mistaken impressions about the seasonal climate forecasts issued by the CPC, including some hydroclimatic researchers. Notably, stakeholders misinterpreted CPC forecast map contours as indicating the severity of conditions expected, thought the "CL" or climatology designation represented a forecast for normal conditions rather than complete forecast uncertainty, and incorrectly interpreted the CPC definitions of wet, dry, and normal.

Discussions with stakeholders from water management, ranching, and wildland fire management sectors revealed tremendous diversity in the climate variables, seasons, forecast lead times, and forecast performance attributes that were considered most important. The water resources management sector is most concerned with periods related to water supplies that originate primarily as mountain snowfall. While rains associated with the summer monsoon typically have little impact on useable water supplies in larger watersheds, their transient local effects are important for stakeholders sensitive to flooding (e.g., emergency managers) or that augment rainfall with contracted water deliveries or groundwater pumping (e.g., irrigation districts). Ranchers tended to be more variable and flexible in their decision making schedules. For them, dry conditions are more problematic than wet, to the extent that ranchers would rather experience false warnings about potentially dry conditions rather than be surprised by their occurrence. The specific seasons of interest to fire management agencies depends on the climate, elevation, and land cover types in their area of jurisdiction, and are especially variable in the Southwest due to the region's tremendous topographic and land cover variation. Which aspects of forecast quality are more important to users depend on the specifics of their decision making situations. Acceptable tradeoffs between contextual specificity (e.g., region, lead time, season) and sufficient sampling differ by users' risk tolerance and are not reliably determined without their input.

The actual and potential role of hydroclimatic forecasts in decision making varies within and across stakeholder sectors. For water resources managers, use of forecasts is affected by the complicated nature of water management, whereby different agencies have different structural, institutional, and legal flexibility to act on seasonal forecasts. Ranchers operate much like emergency water managers in that they consistently attempt to reduce their vulnerability, although for drought rather than flooding. Fire managers are constrained in their use of hydroclimatic forecasts by the bureaucratic budgetary schedule, but with greater administrative flexibility, could use hydroclimatic forecasts to plan prescribed burn programs and post-fire rehabilitation priorities.

While stakeholders clearly differ in the specific opportunities for using hydroclimatic forecasts in their planning and operations, there were also clear commonalities in the constraints that limit the usability of forecasts across all groups. All groups indicated that the lack of ongoing and readily available monitoring of forecast performance limited their confidence and consideration of forecasts. Uniformly, stakeholders understood the difference, and the implications for decision making, between making a forecast for "normal" conditions and withholding of a forecast statement due to total uncertainty. In addition, seasonal forecasts at regional-scales were less usable for most stakeholders, across all groups, than forecasts of events at local scales. Stakeholders in two of the three sectors indicated that forecasts would be more useable if accompanied by more visible historical information. Finally, two sectors expressed difficulty with information overload and their inability to distinguish between "good" and "bad" information and forecast products.

6.3 HYDROCLIMATIC FORECASTS AND FORECASTING

Potential users of hydroclimatic forecasts face a confusing and constantly evolving mix of products issues by many organizations using a variety of media, increasingly including the Internet. The sheer variety of forecast products and sources poses the potential to limit the credibility of any single forecast. The distinction among official, operational, experimental, and research forecasts has practical importance because users now have direct access to all forecast types, each of which represents different levels of uncertainty. Research forecasts may appear attractive to users because they provide higher resolution, longer lead times, or precise quantities rather than categories of conditions or probabilities, but fundamentally they are more speculative than products that have advanced to operational or official status.

Documentation about the forecasts reviewed varied greatly in quality and availability to users; clear documentation about hydrologic forecasts was particularly difficult to obtain. The absence of documentation, describing how expert judgement was incorporated into forecasts or what conditions were used to initialize models, limits opportunities to improve products through retrospective analyses of forecast processes. In addition, information about the quality of actual weather, climate, and hydrologic forecasts is limited. Information about forecast performance that is readily available to potential forecast users and in forms that relate specifically to their decision making situations, is rare to absent. Further, although even the best forecasts can be worthless if users misinterpret them, many forecasts pose difficulties in interpretation. Difficulties concern the meaning of forecast variables (whether associated with probabilities or not), communication of uncertainty that is so great no forecast is possible, and the proper interpretation of base and shifted probabilities.

The ability of scientific advancements to reach stakeholders through operational hydroclimatic forecasts varies significantly. Weather and climate forecast operations are flexible and responsive. They incorporate scientific research findings and products into practice relatively quickly. In addition, they combine results from many NWS models maintained by different units, as well as forecasts generated by non-NWS groups. Forecasters have flexibility to give varying precedence to different forecast techniques in different regions, during different seasons, and for unusual conditions. In contrast, hydrologic forecast operations evolve relatively slowly, with constraints imposed by complex traditional data management systems, longstanding standard operating procedures, and an institutional preference for uniformity in operations. The hydrologic forecasting situation has been frustrating to many members of the hydrologic research community involved in hydrologic process research and model development. Opportunities for relatively rapid improvement of operational hydrologic forecasts, based on recent improvements in climate forecast skill, have been missed because large-scale research programs have been devoted to the next generation of forecast tools and excluded current operational techniques.

6.4 STAKEHOLDER DRIVEN RESEARCH AGENDA

Because they are of common interest to both the hydroclimatic research community and stakeholders concerned with hydroclimatic variability, impacts, or potential responses, forecasts can serve as a key linkage between stakeholders and scientific advances in observations (e.g., snow conditions) or understanding of hydroclimatic processes. For the Southwest, two areas related to hydroclimatic forecasting offer clear promise for societally relevant scientific research: (1) improvement of stakeholder perceptions of forecasts through ongoing forecast assessments, and (2) incremental improvement of seasonal water supply forecasts. The linkages among research topics in the research agenda and demonstration of incremental improvements in forecasts resulting from scientific advancements, using a consistent framework that has meaning to stakeholders, offers the potential for more effective integration of research into resource management practices and policies.

Ongoing forecast assessments can counter poor perceptions of hydroclimatic forecasts that derive from misperceptions about the forecasts and lack of demonstrated forecast quality in ways meaningful to potential users. Forecast assessment addresses qualitative aspects of forecast products as well as quantitative evaluation of forecast performance. Targeted evaluation of forecasts allows users to focus on results not clouded by forecasts they consider irrelevant. By using evaluations that reflect user perspectives, interactions with stakeholders can begin to determine essential forecast attributes; requisite performance thresholds; relationships among forecast quality, utility, and value; and the potential utility and value of forecast improvements. The demonstrated skill, or lack thereof, provides a basis for exploring, with forecast users, forecast performance implications from a context of experience rather than conjecture.

Other hydroclimatic research programs have largely focused on distributed dynamical models of hydroclimatic processes and neglected potential improvements in seasonal water supply forecasts that are, or can be, issued on an operational basis. In contrast, the stakeholder driven research agenda offers the potential to speed the otherwise slow transition of hydrologic modeling improvements into operational forecasting. However, improved predictability without concurrent improvements in stakeholder understanding of the products is insufficient for advanced products to be incorporated into resource management practices and policies on a broad scale. By focusing on incremental improvements in forecasts, the agenda provides opportunities for sustained interactions with stakeholders as new products become available and more effective enumeration of the value of scientific advancements as reflected by improved forecast performance and impacts on resource management decisions.

6.5 FORECAST ASSESSMENT

Organizations that make forecasts publicly available should also provide publicly available evaluations of forecast performance. The evaluations should be accessible to general users when they acquire forecasts, and provide information about forecast performance for the seasons and lead times relevant to the users' situations, using multiple forecast performance measures that reflect user sensitivities to different forecast qualities. Toward that end, forecasters and the research community should jointly establish archives of operational products and ancillary information. The evaluation framework developed in this work equitably accommodates the diversity of stakeholder capabilities through use of multiple evaluation criteria. The framework offers flexibility in making tradeoffs between different levels of informativeness and understandability, and enables users to increase the sophistication of their understanding about climate forecasts, credibility, and implications for decisionmaking.

The diversity of available forecast performance criteria, with each possessing different characteristics and interpretations, presents real potential for confusing forecast users. Evaluation criteria based on contingency tables unfairly neglect the probabilistic character of current forecasts, but are the easiest for users to understand because they simply reflect counts of forecasted and observed conditions that users can easily track. The probability of detection and false alarm rate can directly address specific questions users have about the forecasts, while allowing distinction among important climate conditions. The Brier score and ranked probability scores make clear the potential for users to be disappointed in forecast performance, and ultimately attribute lower credibility to the outlooks than is deserved, when probabilities are converted to categorical forecasts. Further, the ranked probability score is the best summary criteria for evaluating the performance of probabilistic forecasts across entire forecast probability distributions; it is more appropriate in situations where forecast consequences are similar among all climate conditions. Distributions-oriented criteria enable identification of specific situations whereby forecasts perform particularly well or poorly. Obtaining sufficient sample sized for each prospective situation is problematic, however, requiring pragmatic grouping of forecast-observation pairs across multiple regions, lead times, seasons, and distribution categories. Further, the complexity of results probably limits their interpretation by non-specialists. In the Southwest, regional water management agencies are likely to be among the new decision makers with sufficient staff expertise, operational flexibility, and regional purview to make use on conditional distributions-oriented criteria.

Seasonal forecasts, especially those for the Southwest, pose special difficulties for quantitative evaluation. Some difficulties result from the forecasts being limited to average or cumulative conditions over an entire season, when seasonal conditions can be dominated by a single event in the semi-arid Southwest. Further, limited sample sizes compromise even the most mathematically rigorous analyses, spatial and temporal autocorrelation reduce effective sample sizes further, and forecast technologies change faster than sufficient data can accumulate.

Forecast evaluations should focus on specific regions, seasons, and lead times of interest to different decisionmakers. CPC seasonal climate outlooks clearly perform better for some users than others. From the perspective of water managers in the Southwest, winter precipitation outlooks made during fall and winter are better than climatology forecasts according to all criteria. Winter and spring forecasts of summer precipitation lack skill, and in many areas have provided no guidance at all, indicating only "climatology". Compared to the Upper Colorado River Basin, not only does the Lower Basin benefit from greater storage capacity, but from greater climate predictability as well. CPC climate outlooks lack skill when assessed under current decisionmaking schedules used by wildland fire management agencies. However, if schedules are flexible, forecast skill may prove useful where fire risks are affected by winter conditions (e.g., southern California, the Southwest). Cattle ranchers using winter range have greater competitive advantage over those using summer range, due to greater predictability of both seasonal precipitation and temperature.

Review of the CPC seasonal climate outlooks identified several product format limitations. No singular advantage was found for any of several formats in use. However, concentric contours used in CPC outlooks pose interpretation problems not found in alternative products. The most egregious problem is use of the "climatology" designation, causing misinterpretations throughout research, applications, and user communities. The "climatology" designation should be replaced with a more explicit statement of no forecast confidence. Worth considering is revival of the phrase “interdeterminate”, which was used in NWS seasonal climate outlooks issued prior to mid-1982. More generally, forecast product development should involve expertise in visualization and communication, with field testing by a variety of potential users.

6.6 STAKEHOLDER INTERACTIONS

While not initially an objective of this study, the extensive experience with diverse stakeholders in a variety of settings provides insights concerning effective approaches for organizing and conducting stakeholder interactions. Consistent with the findings of Austin et al. (1999), simultaneous interaction with a broad range of stakeholders helps researchers avoid treating stakeholders as isolated entities. Identification of stakeholders' common concerns, interests, and relationships to climate variability and hydroclimatic information led to research activities with broad applicability and easily scalable to include other regions and stakeholders.

Iterative bi-directional interaction with stakeholders, from the outset of a program, is both practical and productive. The public participation model is an effective approach for balancing interaction effort and effectiveness, with targeted engagements of stakeholders allowing discussions to be highly focused and in-depth. Iterative interactions based on demonstrating results from research activities based on stakeholder input enabled significant advances in the complexity of dialogue about issues of hydroclimatic variability, predictability, use of forecasts, and accommodation of uncertainty in making decisions.

Effective stakeholder interaction requires sustained interactions. Once stakeholders have been engaged, there should be programmatic commitment to return to stakeholder groups to show results or explain how their input made a difference in the research. Iterative engagements should take advantage of "natural" opportunities (e.g., regular meetings of stakeholder groups in settings convenient and familiar to them). Funding of stakeholder driven research programs should be sufficient to allow travel to visit remote stakeholders and flexibility to participate in unanticipated, but unique and short-lived, opportunities.

APPENDIX

AGENDA FOR THE CLIMAS FORECAST EVALUATION WORKSHOP

CLIMAS Workshop
Climate Forecasts and Water Management
Institute for the Study of Planet Earth, University of Arizona, Tucson
20 November 2000, Monday, 8:30am – 5pm

8:30AM -- Welcome and Introduction (20 minutes)

- **Welcome, thanks** for participating in CLIMAS, update on CLIMAS activities, explanation of why they were selected to participate in the workshop.
- Where the **facilities** are: restroom, water, etc.
- **Agenda.**
- **Goals** for the workshop. Results will be used to make a difference in production and delivery of climate forecasts (and other kinds of forecasts). We will take their input and use it to develop our prototype interactive forecast evaluation tools.
- They are the first folks to be involved in something like this. It is the first time that we know of where there's been interaction about these things, in this much detail. Pretty much if ANY thing comes out of this, the workshop will have been a success. We'll also consider the effort to be a success if we get through ½ or ¾ of this. And finally, we'll consider it a success if we get feedback on this workshop and are able to use it in subsequent workshops…
- Participant **introductions**. As they go around the room: Have them answer the questions: Have they ever USED any probabilistic forecasts, ever MADE any, ever EVALUATED any…

9AM -- Climate Forecasts: Availability and Interpretation (2 hours)

This section has several goals: to assess several different climate forecasts that have, generally, the same type of content, but in different formats; to assess the CPC probability of exceedance forecasts; to discuss issues about forecast formats and their ease, accuracy, and reliability of interpretation.

(1) CPC official product (high quality map with separate legend), CPC base product (lower quality graphics with interpretation on the map), early version IRI forecasts, current version IRI forecasts, WeatherLabs Inc. (private company producing publically available climate forecasts).
(2) CPC probability of exceedance forecasts and their derived "median quantity" forecasts
(3) Ancillary products

Process for (1): Climate outlook maps

- **Provide** each participant with the first set of forecasts, to spread out in front of them. (*Forecasts: CPC official + legend, CPC base product, early version IRI forecast, current version IRI forecast)*
- Briefly **discuss/explain** each type of forecast.
- **Questions (use notecards):**
  1. What's the forecast for Tucson (or someplace else)?
  2. Looking at official CPC precip forecast, what's prob. That Tucson will be "wet"?
  3. What's the prob. That Tucson will be "dry"?
  4. Which will be wetter: (one place) or (another)?
  5. Looking at IRI forecast: what's the forecast for Tucson?
  6. What's the prob it will be "wet", "dry".
  7. What does "wet" mean? (conceptually, quantitatively)
  8. What does "warm" mean? (conceptually, quantitatively)
- Looking at the group of forecasts, have participants **discuss** what they see as important differences between the forecasts. Follow up with pre-developed points for discussion to ensure that all forecast attributes get discussed.
- **Points for discussion:**
  1. Legend: What's the tradeoff between having a more detailed legend vs. having it separate from the map?
  2. Legend: What are the good/bad qualities of each legend? Too cryptic, too complicated...
  3. Legend: Tradeoff? CPC's fixed probability intervals vs. IRI variable probability intervals
  4. Legend: Is it ok to show prob for 1 category and say how to adjust the others, or is it important to show prob for all categories? (i.e., is it important to show the non-event probability)
  5. Graphics: do they have to be "quality"? (Compare to Weatherlabs forecast, too).
  6. Regions: Does it matter that a region has a sharp boundary? Or is it important to have gradual boundaries?
  7. Regions: Does it matter that a region has a uniform confidence? Or is it important to ID the area of highest confidence?
  8. Is the IRI "D" designation useful/meaningful?
  9. "Climatology": What does the CL mean to you? Why do you think they have that designation?
  10. "Climatology": so what if regions lack a forecast?
  11. "Climatology": what different ways should "no forecast", "no skill", "no confidence", "total uncertainty" be communicated? Is "indeterminate" a good term? ...something else??
- Have participants **rank the forecasts** re: "the best format". *Have each person do their own ranking, then come up and fill in a flipchart matrix: Matrix = columns: each format, rows: each person (no names)*

- **Brainstorm:** Have participants construct a "best" format. *Write everything down on the flipchart.*
- **Summarize** major points and get group's "approval" that the summary really captures the discussion.
- Have participants put forecasts away.

10AM ---------- SHORT BREAK (10 MIN) ------------

10:10AM -- Process for (2): Probability of exceedance forecasts

- **Provide** each participant with second set of forecasts. (*CPC prob of exceedance graphs for precip, temp, for SE AZ, and derived maps for each). Also: have the official CPC forecast that goes along with the POE graphs...*
- **Explain** probability of exceedance graph, with questions/interaction, to make sure everyone understands the graphs. **Explain** the different elements of "content" and "confidence" in this forecast? (Shift in direction of the probabilities, width of the interval, steepening/flattening of the curve)
- **Questions (use notecards):**
  1. What's the forecast for Tucson?
  2. How does the last 10 years compare with the 30 years before that?
  3. What's the probability of having temps over XX degrees? (answer: the probability is a RANGE, not a single value...)
  4. What's the smallest return interval that's important to you? 2-yr, 5-yr, 10-yr, 100-yr?
  5. For 5-yr return interval, that 20% exceedance prob... What precip has the 5-yr return interval? (answer is a RANGE, not a single value)
  6. What's the 20-yr return interval precip (ie. 5% exceedance prob). (answer is: you can't tell from this product!)
- Have participants **discuss** what they see as advantages/limitations of the POE graphs compared to the previous forecasts. Follow up with pre-developed points for discussion to ensure that all concerns get discussed.
- **Points for discussion**
  - Has anyone seen these?
  - What would you do if you got something like this?
  - **Brainstorm**: what are the advantages of this product over the other product? *Write everything down on the flipchart.* How would a product like this help you (given the same "quality" of the forecast...)
  - **Brainstorm**: how would you improve this product's format? *Write everything down on the flipchart.*
- Have participants look at derived **"median quantity" forecast**. Briefly **explain.** Note: when you look at the POE curve, you get a RANGE of values for the median forecast... The map only given one value. The value that is shown on the map is actually associated with a range of probabilities on the POE graph...

- **Questions:**
  7. What's the forecast for Tucson?
  8. What's the probability of occurrence for the value given for Tucson?
- Have participants **discuss** what they see as advantages/limitations of the derived forecasts. Follow up with pre-developed points for discussion to ensure that all concerns get discussed.
- **Points for discussion**
  - Would you use this value directly? Or would you use a range around this value? How would you decide what that range would be?
  - Is it important to have probabilistic forecasts?
  - What probability of occurrence would you give the value in the map?
  - Is 50% probability of being above/below a shifting value the right kind of information for your purposes?
  - How about having different maps for different quantiles? What should those quantiles be? (5,10,15,20,25…) (10,25,50,75,90)??
  - Is it better to have a standard probability and changing values, OR changing probabilities and standard values (e.g., terciles).
- **Summarize** major points developed re: POE graphs and derived forecasts and get group's "approval". Have participants put forecasts away.

10:40AM -------- SHORT BREAK (10 MIN) ------------------ ***See how it's going… take the break before or after #3 Ancillary Information…***

10:50AM -- Process for (3): Ancillary Information

- Can the forecasts stand on their own? Or do they benefit (or require) ancillary information?
- What sort of ancillary information is important to include with the forecasts? Should any of these be on/in the forecast products? Present/discuss the following items. Are there others? **Brainstorm**, then **ranking** *Have each person do their own ranking, then come up and fill in a flipchart matrix: Matrix = columns: each ancillary item, rows: each person (no names)*
  - Historic context: recent (last 5 years, last 10 years, climatology period [61-90, 71-00]?
  - Historic context: similar years (El Nino, La Nina, non-Nino, PDO +/-, following wet winters vs. following dry winters)
  - Historic context: period-of-record
  - Pre-historic context: any prior information, paleo-information
  - Forecast rationale: what techniques dominate the forecast
  - Forecast rationale: what thinking drives the specified forecast uncertainty
  - Forecast performance: for individual techniques, for past forecasts. We'll spend more time on this the rest of the day…

11:15 AM -- What Makes a Forecast "Good" or "Bad"? (20-25 minutes)
The goal of this section is to get some idea, before looking at any results, about what participants think are important attributes of climate forecasts (i.e., probabilistic forecasts).

- **Discuss** the general question. Follow up with pre-developed points for discussion to ensure that all concerns get discussed.
- If specific elements come up, have participants rank them by importance. *List items on flipchart, review. Have each person do their own ranking, then come up and fill in a flipchart matrix: Matrix = columns: each element, rows: each person (no names)*
- **Summarize** and get group's approval.

Points for Discussion

1. What are the critical questions the participants want answered by a forecast?
2. How about: Will the forecast warn me of an impending critical event?
3. How about: Given a forecast showing enhanced probability of a critical event, can I trust that forecast?
4. Which kinds of decisionmakers are more interested in "normal" conditions, specific "extremes", or the entire distribution of conditions?
5. Do you make decisions based on "expected value"? Do those decisions consider "variance" around the expected value? If yes for either one, then does that mean that having "unbiased" forecasts is the critical thing?
6. Which kinds of decisionmakers focus on optimizing results, satisfying certain conditions, or avoiding mistakes?

11:40AM -- Issues in "Valid" Forecast Evaluation (20-25 mintues)
The goal of this section is to address some of the problems that exist in evaluations of long-term forecasts. *Not going to do anything "fancy" here, just sit and talk. Have someone taking notes!! DO put major points on the flipcharts...*

- **Solicit** their insight/experience with forecast evaluations they are familiar with and (un)comfortable with.
- **Discuss** the idea of comparing forecasts and observations, one-on-one, and their "comfort" with that.
- **Discuss** Do the limited sample sizes bother you? What about the lack of independence in the data (both forecasts and observations)? What does that mean for your acceptance/skepticism of any evaluations?
- **Discuss** the idea that the technology for making climate forecasts is changing faster than statistically-valid experience accumulates (over time, the forecasts are not coming from the same population), and what that means for their acceptance/skepticism of any climate forecasts.
- **Discuss** the tradeoff of time versus space in evaluating climate forecasts (i.e., increasing sample size of short time series of climate forecasts by using larger/more regions in the evaluations).
- **Discuss** What role should evaluations of individual techniques have in expressing forecast quality? Individual techniques can be assessed via reanalysis, but forecasts

are subjective combinations of those techniques and forecaster expertise/judgement. One option might be that forecasters explicitly identify the techniques used in a forecast (but that would be required for each region and leadtime) and then weight the individual evaluations in the same way forecasters weighted the techniques.

- **Discuss** But then what if recent conditions are different than the techniques were developed for? We may have that issue arising re: temperatures (as they'll see in some plots).
- **Summarize** major points and get group's "approval".

-------- LUNCH (45 MINUTES) --------------- NOON – 12:45

12:50PM -- Decision Calendars (10-20 minutes)

The goal of this section is to determine an effective format for users to communicate their decision calendars. Potential formats include inner/outer decision wheels, a pair of decision wheels, a pair of timelines, *other suggestions?* This should be a fairly short exercise.

- **Explain** the concept of decision calendars; discuss briefly to make sure everyone understands.
- **Provide** each participant with a set of potential formats for indicating their decision calendars.
- Have them identify their decision calendars using each format.
- Discuss good/bad points of each format.
- Have participants **rank** options re: "the best format" and **brainstorm** about improvements.
- **Summarize** major points and get group's "approval" and have participants put away decision calendars.

1 PM -- Graphical Comparison of Forecasts and Observations (1 hour)

The goal of this section is to get some feedback about the "bubble plots" that show the historic record of CPC climate forecasts (a series of temporally evolving probabilistic forecasts) and observations.

- **Provide** each participant with a set of *bubble plots (southeast Arizona, precipitation and temperature) and the map showing the 102 CPC regions.*
- **Explain** bubble plots, with questions/interaction, to make sure everyone understands it.
- **Questions:**
  1. For southeast Arizona precipitation: What was the evolution of forecasts for the period JAS 1996? (all "climatology")
  2. For southeast Arizona precipitation: what's the MOST confident forecast that was ever made? (3% prob. of falling above the wet tercile boundary). When was it made, and for what period was it made? (forecast covers ASO 1998, issued in JUNE 1998). What actually happened? It was dry.

3. What was the 2nd-most confident forecast? 3% prob. of falling below the dry tercile boundary, forecast covers JFM 1998, issued in October 1997). What condition actually happened for the forecast? It was wet.
4. How would you characterize winter 1997-98? (Consistently wet in each 3-month season).
5. How would you characterize January 1998? (Dry!)
6. For NW AZ/S NV temperature, what's the most confident forecast that's been made? 3% prob of being cold, forecast covering JFM 1999, issued in December 1998.

- **Discuss** what's clear/not clear about the graphics.
- Have participants **brainstorm** about improvements.
- **Summarize** "graphical format" discussion and get group's approval.
- **Provide** participants with other bubble plots, to spread out in front of them (*precipitation only for northeast Utah and west Texas; precip and temperature for all the Arizona regions).*
- **Return flipchart** about "what makes a forecast good or bad". Looking at these items, and looking at the group of precipitation bubble plots, have participants **discuss** what they see as important differences between them. Follow up with pre-developed points for discussion to ensure that all forecast attributes get discussed (e.g., sharpness, consistency, *to be expanded).*
- **Points for Discussion**
  1. Does it bother you to see forecasts compared to observations in a graph? We've had some folks react strongly to this kid of plot…
  2. What can you say about performance *in the specific single-forecast case?*
  3. What can you say about performance *in the aggregate?*
  4. What can you say about the ability/willingness of CPC to actually make a forecast for SE AZ compared to NE UT? What does this say about *sharpness/resolution* of the forecasts?
  5. What might you say about the *consistency* of the forecasts? Where did the forecasts wobble? (for SE AZ: MAM 1996, NDJ 99/00)
  6. What can you say about the performance of the forecast for SE AZ compared to W TX?
  7. What can you say about the uniqueness of the conditions over the evaluation period? Take a look at the temperature plots!! What sort of difficulty does this present in evaluation?
- **Summarize** discussion about what aspects of the forecasts are important. Get group's approval that the summary really captures the discussion. Have participants put plots away.

------------- SHORT BREAK (10 MIN) -------------

1:15PM -- Quantitative Forecast Evaluation: Appropriate Criteria, with Applications (2 hours)

The goal of this section is to assess different forecast evaluation criteria for current-generation climate forecasts (i.e., probabilities for tercile categories).

- Discussion of each criteria will revolve around one example, using relevant bubble plots that show only those forecasts included in the example. Need to include examples for multiple regions (Upper Colorado and Lower Colorado) for addressing issues of sufficient sample size for some criteria.
- **Provide** each participant with bubble plot. *Subsetted bubble plot for SE AZ precipitation. Wworksheets for each criteria (POD, FAR, Brier Score, Ranked Probability Score). Packet should also include forecast evaluation figures (national maps for Water Management Scenario 2: POD/FAR, Brier Score, RPS), Figures 16 and 17 (discrimination and reliability diagrams).*
- For each criteria, **explain** it and work through an example with the bubble plot, with questions/interaction to make sure each participant understands the criteria. Also work through the "climatologic"/base rate example for that criteria.
- Then **show** the national map related to that score.
- Use *overhead transparencies* of the bubble plots, and the specific example bubble plot, to explain and compare each criteria.
  1. Probability of Detection **(POD)** and False Alarm Rate **(FAR)**. Converts probabilistic forecasts into categorical forecasts (100% probability); easy to compute using contingency tables. Focuses only on specific conditions (tercile categories) *.POD & FAR just deal with "above/below the 33% line" and color.*
  2. **Brier Score** Accounts for stated probabilities; conceptual progression from POD and FAR. Focuses only on specific conditions (tercile categories). *Brier Score deals with "how much above/below the 33% line" and was it the right color.*
  3. **Rank Probability Score**. Accounts for stated probabilities; conceptual progression from Brier Score because it considers the distribution of stated probabilities. Summarizes results across all tercile categories, but can't pull out specific tercile conditions. *RPS deals with "how much above/below the 33% line and which color.*
  4. **Distributional analysis**. Conceptually and graphically more complex, but more informative about forecast/observation details. Can focus on specific joint, conditional, and/or marginal probabilities to distinguish among various aspects of forecast quality. *Distributional Analysis tries to create many different distributions from the various bubbles*
     - Marginal distribution of observations = histogram of the colors (Shows the distribution of actual conditions during the period of the evaluation) = **uncertainty = variance of observations**
     - Marginal distribution of forecasts = histogram of the probability values = **sharpness = refinement**
     - Conditional distribution of the forecasts, given the observations = sort by color and look at the strength of the probabilities for that color =

Discrimination says that if you have different colors, your probability distribution should be different! **Figure 16** If the forecast probabilities are similar, for widely different conditions (i.e., wet and dry terciles), then the forecasts don't have good discrimination capabilities.

- Conditional distribution of the observations, given the forecasts = sort by strength of probability and look at the colors = **Reliability = calibration** says that the stronger the probability, the most often the color should be right (Low probability forecasts are right less often than high probability forecasts). **Figure 17**

- Looking at the group of criteria, have participants **discuss** what they see as important differences between them. Follow up with pre-developed points for discussion to ensure that all issues get discussed.
- Have participants **rank** the criteria re: "the best format" for specific types of situations/users.
- **Summarize** major points and get group's "approval" that the summary really captures the discussion. Have participants put materials away.

Points for Discussion

1. Advantages/disadvantages of using criteria values alone versus comparing with the "climatology"/base rate (i.e., the best alternative forecast).
2. **For each measure**, is it too simplistic? Too complex? Similar to another measure that would be more preferable? Why would some other measure be better?
3. Are these measures too simplistic? What about Bayesian analysis, that would allow adjustment of the forecasts based on their prior performance?
4. Current forecasts are issued for tercile categories. What parts of forecast/observation distributions are preferred? Given the Probability of Exceedance Forecasts (provide one/several examples) what portions of the distribution are important to different situations/users?

---------------- **BREAK (15 MIN)** -----------------

3:30PM -- *Revisit Some Earlier Issues (20 minutes)*

The goal of this section is to re-address some issues brought up earlier, to see if participants have more advanced thinking/insights after actually working through the graphical and quantitative evaluations.

(1) What makes a forecast "good" or "bad"?

(2) Issues in valid forecast evaluation

Each question is addressed in turn.

- *Bring back major points (on large flipcharts)* from earlier discussion on that question. **Review and ask** whether there's any change in thinking, anything to remove/restate, anything to add.
- **Summarize** and get group's approval on final result.

4PM -- Implications of Present Forecast Quality (20 minutes)

The goal of this section is to build on the common language and understanding developed so far, to explore how good climate forecasts must be before they are useful for water management.

- *Bring back major points (on large flipcharts)* from earlier discussion about evaluation criteria, and have participants return to their materials from that section.
- **Discuss**, for their situation and those of other water management concerns, how good is good enough?
- Which criteria would you look at in deciding to accept/reject?
- How would they go about determining threshold values?
- At what level would they accept/reject forecasts?
- Is there anything analogous (i.e., deciding when to accept/hold off) for other "advanced/new technologies"?
- **Summarize** points and get group's approval. Have participants put materials away.

4:30PM -- Closing (20 minutes)

The goal of this section is to bring the whole effort together and have participants see the contribution they've made through the workshop.

- *Bring back major points (on large flipcharts)* from earlier sections. **Briefly review**.
- **Thank them** for their participation and the progress that's been made through their focused effort. Results will be used to make a difference in production and delivery of climate forecasts (and other kinds of forecasts).
- We will take their input and use it to develop out prototype interactive forecast evaluation tools. We will contact them later with a web address where they can try it out.
- They can keep all the materials they've used today.
- **Provide** *them with a piece of paper and envelope, to make comments and then mail them back... (They can be anonymous with their comments).*
- Reiterate their importance to CLIMAS.
- **Thanks again and have a good trip home!**

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