Understanding the Climate-Sensitive Decisions and Information Needs of Freshwater Resource Managers in Hawaii

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ABSTRACT

Understanding how climate science can be useful in decisions about the management of freshwater resources requires knowledge of decision makers, their climate-sensitive decisions, and the context in which the decisions are being made. A mixed-methods study found that people managing freshwater resources in Hawaii are highly educated and experienced in diverse professions, they perceive climate change as posing a worrisome risk, and they would like to be better informed about how to adapt to climate change. Decision makers with higher climate literacy seem to be more comfortable dealing with uncertain information. Those with lower climate literacy seem to be more trusting of climate information from familiar sources. Freshwater managers in Hawaii make a wide range of climate-sensitive decisions. These decisions can be characterized on several key dimensions including purpose (optimization and evaluation), time horizon (short term and long term), level of information uncertainty (known, uncertain, deeply uncertain, and completely unknown), and information type (quantitative and qualitative). The climate information most relevant to decision makers includes vulnerability assessments incorporating long-term projections about temperature, rainfall distribution, storms, sea level rise, and streamflow changes at an island or statewide scale. The main barriers to using available climate information include insufficient staff time to locate the information and the lack of a clear legal mandate to use the information. Overall, the results suggest that an integrated and systematic approach is needed to determine where and when uncertain climate information is useful and how a larger set of organizational and individual variables affect decision making.

1. Introduction

Freshwater resources are critical for Pacific islands and their communities. Surface water is limited on many islands, if it exists at all, and aquifers are small and fragile, threatened by increasing demand and saltwater intrusion. The recent Pacific Islands Regional Climate Assessment (Keener et al. 2012a) suggests that freshwater managers responsible for providing island communities with an adequate water supply may encounter significant challenges in the face of climate change. Increasing air temperatures and changing rainfall patterns will make freshwater more scarce on many Pacific islands. When the quality and quantity of available water are affected by climatic events, island economies, environments, and public health are at risk. Many Pacific island agencies lack, but want, better guidance for their efforts aimed at assessing and predicting water resources, justifying planning actions, and evaluating water usage plans (Anderson et al. 2007; Keener et al. 2012b; Shea et al. 2001).

To ensure a sustainable supply and equitable distribution of freshwater, management decisions must take into account how the recharging of aquifers and streams may be altered under future climate conditions. Climate science is limited, however, in what it can tell us about how global climate change will alter local air or water temperatures, rainfall, storms, or sea level, especially at spatial and temporal time scales most relevant to natural resource decision makers. Consequently, the impact of climate change on freshwater resources is uncertain. In the absence of precise climate projections, government agencies, businesses, and others need to strengthen the

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decision processes that establish priorities for policy making, research, training, and outreach activities.

One way to strengthen decisions under conditions of uncertainty is to identify what types of decisions may be sensitive to climatic changes, who is making these decisions, and what the context is in which these decision processes are occurring. For instance, decisions about where to drill wells for future withdrawals depend on estimates of the sustainable yields of aquifers, which in turn depend on the extent to which decision makers [such as those in a state agency such as the Department of Land and Natural Resources (DLNR)] are able to make accurate assumptions about the amount and distribution of future rainfall. Being able to characterize such climate-sensitive decisions about freshwater resources will help identify what information is needed and when, at what resolution and timeframe. Also, knowing when and to what extent uncertainty in climate science matters to (or is legally required to be considered by) decision makers will clarify the amount and type of uncertainty analysis needed. In short, understanding climate-sensitive decisions is critical for effectively connecting climate information with decision makers' needs (Moser 2012; Moser and Dilling 2007; Pielke 2007; Pulwarty et al. 2010).

A framework for research aimed at understanding climate-sensitive decisions and information needs can be drawn from the field of behavioral decision making. Several decades of research show that decisions involving uncertain information are influenced by variables related to three main categories: 1) the decision maker (e.g., education and experience), 2) the decision information (e.g., complexity and framing), and 3) the decision context (e.g., decision support and social norms; Lichtenstein and Slovic 2006). Understanding relevant variables in each of these categories is important because according to the ''person-task fit framework'' (PTF; Finucane et al. 2005), a good decision is more likely to result when features of the decision maker meet the demands of the task or context. For instance, a person with higher education and more experience directly related to the decision at hand will be more able to understand complex information in the absence of a decision support system. By focusing on the relevant characteristics of the decision maker and task, and how these factors interact, the PTF framework enables us to describe how different decision makers might make better or worse decisions, given various decision contexts. Using this framework, we can systematically characterize relevant aspects of decision makers and their decisions about freshwater management to help us determine the usefulness of climate information in their decision-making processes.

The PTF framework is consistent with Moser's (2012) integrated Decision Uncertainty Screening Tool (DUST), which is designed to help link scientific analysis with the use of information by identifying climate information needs in the course of decision making. DUST adapts Jones et al. (1999)'s conditions of usefulness (relevance, compatibility, accessibility, and receptivity) to determine whether scientific information is meeting decision makers' needs. A core component of DUST is that it classifies decisions, highlighting key dimensions (or attributes) of the decision problem alongside contextual constraints. For instance, one dimension distinguishes optimization decisions (identifying strategies to produce desired outcomes) versus evaluation decisions (evaluating the outcomes of given strategies). Another dimension distinguishes the decision timeframe as short term (seasonal to a few years) versus long term (decades). Contextual constraints include social, technical, economic, or political factors that arise in the context in which the decision is being made. Similar to the PTF framework, DUST emphasizes an integrative approach that shifts the focus to the decision maker, the decision-making process or problem, and the context in which climate information may or may not be useful.

The main objective of the research reported in this paper is to characterize the climate-sensitive decisions being made by freshwater managers in Hawaii (with a focus on the central Oahu watershed) and what information is needed to support those decisions. Specifically, we addressed six research questions organized under the PTF and DUST frameworks to obtain information about the decision makers, the decision problems, and the decision context relevant to freshwater management under a changing climate. Research questions about the decision makers include:

1) What are the decision makers' perceptions of and concerns about climate change impacts, especially related to the management of freshwater resources?
2) What capacity do decision makers have to use climate information to support their adaptation decisions?

Research questions about the decision problems include:

3) What climate-sensitive decisions are decision makers currently facing or likely to be facing in the future related to freshwater resources?
4) What are the key dimensions of these climate-sensitive decisions?

Research questions about the decision context include:

5) What information and analyses are needed to support decision makers' climate-sensitive assessments and decision-making processes?
6) What are the barriers to using climate information and what are the trusted sources of information about the impacts of climate variability and change?

2. Methods

The research was approved by the East-West Center's Institutional Review Board.

a. Geographical scope

The geographical scope of this study includes the islands of the Hawaiian archipelago, with specific focus on the central Oahu watershed. This watershed includes the Pearl Harbor aquifer, which serves most of the 976 372 people who reside on the island of Oahu (U.S. Census Bureau 2012) and the 7.3 million tourists who visit annually (Hawaii Tourism Authority 2012). Most sources agree that existing permit allocations for the Pearl Harbor aquifer are close to the aquifer's sustainable yield (Wilson Okamoto Corporation 2008). Demand for water is expected to increase with population growth, new construction, and military uses. In a freshwater lens system like the Pearl Harbor aquifer, increased withdrawals will, in the long term, result in a decline in water levels, an increase in the size of the brackish transition zone between freshwater and saltwater, and a reduction of natural groundwater discharge to the ocean. The extent to which water levels decline and the transition zone grows is dependent on several factors including the distribution and rates of withdrawals, the hydraulic characteristics of the aquifer system, and future changes in climate.

b. Participants

1) Interview participants

The interview sample included 23 individuals (see Table 1) recruited from a range of organizations and public agencies that are interested in, affected by, or could affect the management of freshwater resources in the central Oahu watershed. Relevant organizations and agencies were selected from the comprehensive list of stakeholders identified in the *Final Report on the Central Oahu Watershed Study* (Oceanit et al. 2007) and from references made by individuals within those agencies. Interviewees represented the federal government [U.S. Army Garrison, U.S. Army Corps of Engineers (USACE), U.S. Department of Agriculture (USDA), and U.S. Navy]; Hawaii state government (Department of Health, Department of Land and Natural Resources, Department of Agriculture, watershed partnerships, and state legislature); city and county of Honolulu [Department of Planning and Permitting (DPP) and neighborhood boards]; and private enterprises (utilities, property developers, farms, museums, and schools).

2) Workshop participants

The workshop participants included 22 individuals (see Table 1) recruited from a range of organizations and public agencies that are interested in, affected by, or could affect the management of freshwater resources in the central Oahu watershed. Relevant organizations and agencies were selected from the interview sample (described above) and from references made by individuals from those agencies. Almost 32% of workshop participants had participated in an earlier interview. Inviting the same individuals to participate in the interviews and workshops allowed the researchers to 1) elicit new information in reaction to interview findings, 2) evaluate whether participants' views had been captured accurately,

TABLE 1. Participant characteristics.

	Interviews*	Workshops**
Years resident in Hawaii, range (mean)	5–60 (37.7)	1–56 (31.1)
Years in current profession, range (mean)	1–40 (19.4)	2–40 (18.5)
Years in current position, range (mean)	0.2–18 (5.5)	0.2–20 (4.6)
Gender, *n* (%)		
Male	20 (87)	15 (68)
Female	3 (13)	7 (32)
Education, *n* (%)		
Some college or 2-yr degree	1 (4)	1 (5)
4-yr college graduate	3 (13)	6 (27)
More than 4-yr college degree	18 (78)	11 (50)
Ethnicity, *n* (%)		
White	10 (43)	7 (32)
Japanese	4 (17)	4 (18)
Chinese	3 (13)	3 (13)
Native Hawaiian	2 (9)	0 (0)
Samoan	1 (4)	0 (0)
Filipino	0 (0)	1 (5)
Hispanic or Latino	0 (0)	1 (5)
Other	1 (4)	0 (0)
Occupation, *n* (%)		
Project or resource manager	10 (43)	3 (14)
Engineer (e.g., civil, environmental)	5 (22)	3 (14)
Planner (e.g., land use, urban, environmental)	3 (13)	7 (32)
Director	4 (18)	4 (18)
Other	1 (4)	2 (9)
Organization, *n* (%)		
Private (utilities, developers, land owners, museum)	8 (35)	4 (18)
Federal government	7 (30)	3 (14)
State government	6 (26)	12 (55)
County and city government	2 (9)	3 (14)

* Total number of interview participants = 23. Percentages add to less than 100 because one interviewee was not a resident of Hawaii, one interviewee did not indicate a main ethnicity, and one interviewee was missing data on all variables except gender, occupation, and type of organization.

** Total number of workshop participants = 22. Percentages will add to less than 100 because some data for education, ethnicity, and occupation are missing.

and 3) explore in more detail specific areas of discourse that were identified in the interviews as important and complex. An additional five people attended the workshops as observers (two from American Sāmoa, two from Guam, and one from Arizona). Nine members of the Pacific Regional Integrated Sciences and Assessments research program also attended the workshops.

3) Survey participants

Following the sampling procedure used for the interview participants described above, e-mail or telephone invitations to participate in an online survey were sent to 147 individuals employed by federal, state, and city and county government agencies and private organizations identified as interested in, affected by, or able to affect the management of freshwater resources in the central Oahu watershed. As above, relevant organizations and agencies were selected from the comprehensive list of stakeholders identified in the *Final Report on the Central Oahu Watershed Study* (Oceanit et al. 2007) and from references made by individuals within those agencies. Invitations to participate in the survey were sent via e-mail. Nonrespondents were followed up with one e-mail reminder and one telephone reminder. Fifty people (34% response rate) responded to the survey online. Analyses were conducted on the 43 completed surveys received (65% male; mean age = 51.4 yr; 79% held more than 4-yr college degree). The main ethnicities of respondents included white (39%), Native Hawaiian (16%), Japanese (16%), and Chinese (11%). The main professional groups included environmental scientists (23%), project or resource managers (21%), planners (12%), and engineers (9%). Respondents had resided in Hawaii between 1 to 70 yr (mean = 39.5 yr). They had been in their professions 4 to 45 yr (mean = 20.3 yr) and in their current positions 0 to 34 yr (mean = 8.0 yr).

c. Materials and procedures

1) Interview materials and procedures

During in-depth interviews, researchers guide discussions by introducing a series of prepared open- and closed-ended questions designed to elicit factual information on behavior or events as well as on participants' knowledge, beliefs, and attitudes about particular topics. This type of interview differs from structured interviewing in that the agenda of the interviews is flexible in order to uncover and explore new areas or ideas that were not anticipated at the onset of research (Bernard 1994; Britten 1995). In this study, a standard protocol was developed to ensure that the same issues were discussed in all interviews. A funneling technique was followed during questioning, starting with a broad question that encompassed the issue of interest but avoided prejudging the answer (Morgan 1998; O'Brien 1994; Pope and Mays 1995).

Participants were first asked to describe their organizations' responsibilities in managing freshwater resources and the nature of the specific decisions involved. Then they were asked to describe how the management of freshwater resources is sensitive to variations in climate and how that might affect their decisions about how to sustainably manage the resource. Next, participants were asked about their familiarity with climate change information, where they get this type of information, and what kind of information they need to support their decisions. Participants were also asked about how uncertainty in information affects their ability to use it. Finally, participants were asked to identify plans, policies, regulations, and laws that were relevant to their decision making and any constraints these placed on their responses to climate change impacts.

The order of questions varied in response to participant contributions, as did the number and type of probes needed to elicit additional information. Each interview was about 1 hour in length and was audio recorded (one exception was a participant who submitted a written statement). All audio recordings of individual interviews were transcribed verbatim. Qualitative theme analysis (Bernard and Ryan 1998; Crabtree and Miller 1992) of interview transcripts was used to distinguish salient constructs and issues and to identify keywords or phrases commonly used to describe attitudes and experiences. Using the keywords-in-context technique (Tesch 1990), each transcript was searched to find instances of keywords or phrases. Themes were then identified by electronically sorting the examples into groups of similar meaning, while retaining information about the sources of the examples. All transcripts were read by two authors; core themes that repeatedly appeared in the data were identified by Finucane and confirmed by Corlew. Consensus on common and differentiating themes was achieved via discussion. Field notes documented information outside the audiotaped record, such as observations about the participant and nonverbal communication (e.g., gestures) that took place during the interview.

2) Workshop materials and procedures

Information obtained from the in-depth interviews was used to design the materials and methods for the two workshops held on 8 and 15 July 2011. The main goal of the workshops was to engage decision makers from government and nongovernment organizations in a collaborative deliberation on key questions related to climate change impacts on freshwater sustainability and how these questions need to be answered. The three key objectives of the workshops were to 1) share current knowledge about climate change and its potential impacts on freshwater resources in Hawaii, 2) identify priority issues related to managing freshwater resources under a changing climate, and 3) identify needs (informational, organizational, legal, etc.) for successfully managing freshwater resources under a changing climate.

Both day-long workshops were professionally facilitated. The agenda included an introductory presentation (describing the study motivations, key findings from the prior interviews, and the workshop objectives) and a presentation on observed climate trends in Hawaii (temperature, precipitation, stream base flow, trade wind inversion, potential decoupling between Hawaiian rainfall patterns and the Pacific decadal oscillation, implications for the lifting condensation level, evapotranspiration, and solar radiation). The remaining time was a facilitated discussion to address 1) knowledge needs and the availability of information for preparing for impacts; 2) organizational, political, and other challenges faced when gathering and using information; and 3) how to overcome barriers to information use.

Before leaving the workshops, participants were asked to complete a short evaluation survey. Two items used four-point scales to assess participants' 1) overall evaluation of the workshop (extremely useful, moderately useful, a little useful, and not at all useful) and 2) perceived relevance of the workshop to their job or profession (extremely relevant, moderately relevant, a little relevant, and not at all relevant). Two items used a three-point scale to assess whether participants thought the workshop changed their 1) understanding of the impacts of climate change on water responses in Hawaii and 2) ability to connect climate change to their job responsibilities (response options included decreased, no change, and improved). Open-ended items on the evaluation survey requested suggestions for improving the workshop and specific information needs.

3) Online survey materials and procedures

An online survey was conducted 7 September–20 October 2011 using the SurveyGizmo online survey software tool. When participants opened the survey, they were first shown an informed consent briefing page that described the purpose of the study, the survey process, confidentiality, and who to contact with questions or concerns. They were also provided definitions of climate, climate variability, climate change, and freshwater resources. The central Oahu watershed was defined and accompanied by a map of the area.

Initial survey items were designed to capture quantitative information about decision makers' perceptions of climate change and its impacts on freshwater resources in the central Oahu watershed. Subsequent items assessed climate literacy using items adapted from previous research (Bord et al. 2000; Leiserowitz and Smith 2010; Reynolds et al. 2010). Next, participants were asked about what type of climate information they needed, at what scale climate information is most relevant, and what sources of climate information are relied on and perceived as trustworthy. Participants were asked to indicate how uncertainty affected their ability to use climate information and their reasons for not using available climate information. They were also asked about water use priorities and which considerations should drive decisions about the management of freshwater resources. Finally, demographic information was collected. The wording of the survey questions and response scales is provided in the next section as findings are presented in the text and tables.

3. Findings

The findings are organized under the PTF and DUST frameworks presented in the introduction to address the specific research questions about decision makers, decision problems, and decision contexts.

a. *Characteristics of decision makers*

1) What are decision makers' perceptions of and concerns about climate change impacts, especially related to the management of freshwater resources?

Qualitative analyses of transcripts revealed that all interviewees perceived that climate change poses a risk to freshwater resources. Interviewees' main concern about climate impacts related to anticipating what freshwater will be available in the long term (amount, when, for how long, and where) in order to decide how to meet the freshwater needs of diverse users in future decades. Workshop discussions confirmed the interview findings about climate change risk perceptions and concerns for freshwater resources.

Additionally, qualitative analyses of interview transcripts revealed that the nature of individuals' concerns differed depending on their responsibilities. For instance, individuals from federal agencies responsible for disaster risk reduction expressed the most concern about changes in heavy rainfall events, whereas individuals from state and city and county agencies and some

TABLE 2. How likely do you think it is that each of the following will occur in Hawaii during the next 50 years as a result of climate change ($n = 43$)? Note that missing data ($n = 1$ for all items, except rates of disease where $n = 2$) mean that percentages will add to less than 100.

	Not at all likely (%)	Somewhat likely (%)	Very likely (%)	Extremely likely (%)	Do not know (%)
Sea level rise	2	12	39	44	2
Worse droughts	2	21	42	33	0
Saltwater intrusion into groundwater	2	28	28	30	9
Worse storms and hurricanes	5	26	39	26	2
Water shortages	2	28	44	23	0
Worse flooding of cities	7	23	46	21	0
Food shortages	7	53	19	14	5
Increased rates of disease	14	23	28	12	19

private enterprises who are responsible for community planning, infrastructure development, and ecosystem conservation expressed concern about both droughts and floods. Individuals responsible for food security (e.g., federal and state agriculture departments and farmers) were concerned primarily about droughts.

Survey results provided more detail about the perceptions of the likelihood and consequences of climate change impacts on freshwater resources. When asked how convinced they are that the climate is changing because of greenhouse gas emissions, the majority of participants indicated that they were ‘‘completely convinced’’ (53%) or ‘‘mostly convinced’’ (33%); only a few participants were ‘‘not so convinced’’ (14%). When asked whether climate change will have a dangerous impact on freshwater resources in the central Oahu watershed, some survey participants suggested that ‘‘no, it is not dangerous’’ (2%) or ‘‘yes, it is dangerous now’’(14%), whereas most suggested that it would be dangerous in 10 yr (21%), 25 yr (35%), 50 yr (12%), or 100 yr (5%); a small proportion indicated that they ‘‘do not know’’(9%). Survey participants indicated that a range of climate change impacts were ‘‘very likely’’ or ‘‘extremely likely’’ to occur in Hawaii in the next 50 yr, including worse storms, hurricanes, droughts, flooding, saltwater intrusion into groundwater, water shortages, and sea level rise (see Table 2). The majority of survey participants expected that climate change would lead to less freshwater resources being available in the central Oahu watershed (84%) and that the quality of the water would be worse (74%).

When asked to rate their worry about the impacts of climate change on freshwater resources in the central Oahu watershed on a four-point scale, most survey participants indicated they were ‘‘very worried’’ (35%) or ‘‘moderately worried’’ (39%) and fewer said they were ‘‘a little worried’’ (23%) or ‘‘not at all worried’’ (2%). Survey participants were most concerned about future generations, agriculture, native plants and animals, and their community (see Table 3).

2) WHAT CAPACITY DO DECISION MAKERS HAVE TO USE CLIMATE INFORMATION TO SUPPORT THEIR ADAPTATION DECISIONS?

When asked how informed they were on a four-point scale (not at all, not very well, fairly well, and very well), about half of the survey participants indicated that they were ‘‘fairly well informed’’ about the likelihood (51%) and consequences (53%) of climate variability and change for freshwater resources in the central Oahu watershed. However, about half of the survey participants (51%) indicated they were ‘‘not very well informed’’

TABLE 3. Assuming climate change will have an impact on freshwater resources in the central Oahu watershed, how concerned are you for the following ($n = 43$)?

	Not at all concerned (%)	Somewhat concerned (%)	Very concerned (%)	Extremely concerned (%)
Future generations of people	2	26	46	26
Agriculture	5	14	58	23
Native plant and animal species	5	42	35	19
Your community	2	48	37	12
You personally	12	53	23	12
Native Hawaiian traditional access and practices	12	58	16	14
Industry	23	44	26	7

TABLE 4. Percent of respondents scoring correctly on climate literacy items (the correct answer is given after each item) (n = 43). Note that data are missing for item 6 (n = 1).

	Percent (%) scoring correctly
1. In your view, do most scientists agree or disagree with one another about whether climate change is happening? (agree)	72
2. Weather changes from year to year. (true)	91
3. Climate changes from year to year. (false)	65
4. Climate means the average weather conditions in a region. (true)	81
5. Ocean currents carry heat from the equator toward the north and south poles. (true)	86
6. The greenhouse effect keeps the earth from being as cold as outer space. (true)	84
7. The temperature of the earth is affected by whether the earth's surface is light or dark colored. (true)	77
8. A major cause of climate change is pollution/emissions from business and industry. (true)	74
9. A major cause of climate change is the use of aerosol spray cans. (false)	63
10. A major cause of climate change is electrical generation from fossil fuels such as coal. (true)	79
11. If we were to stop burning fossil fuels today, the amount of carbon dioxide in the atmosphere would decrease almost immediately. (false)	79
12. If we were to stop burning fossil fuels today, global warming would stop almost immediately. (false)	93
13. Climate change will cause some places to get wetter, while others will get drier. (true)	98
14. Climate change will increase crop yields in some places, and decrease it in others. (true)	93
15. Climate change will cause temperatures to increase by roughly the same amount in all countries. (false)	93

about how to prepare for changes to freshwater resources in the watershed as a result of the changing climate.

We calculated a climate literacy index score for each survey respondent based on 15 items (see Table 4). Overall, climate literacy was high [mean = 12.3, mean rank (SD) = 2.3]. A high percentage believed incorrectly that there is still a lot of disagreement among scientists about whether or not climate change is happening (item 1) and that a major cause of climate change is the use of aerosol spray cans (item 9).

Based on a median split of the index scores, we created lower and higher climate literacy groups. Table 5 shows that compared with people with lower climate literacy, those with higher climate literacy seem less likely to require high (>90%) certainty (item 5) and less likely to postpone decisions in the face of uncertainty (item 6).

b. *Characteristics of decision problems*

1) WHAT CLIMATE-SENSITIVE DECISIONS ARE DECISION MAKERS CURRENTLY FACING OR LIKELY TO BE FACING IN THE FUTURE RELATED TO FRESHWATER RESOURCES?

Specific examples of climate-sensitive decisions were revealed in the interview transcripts. As illustrated in Tables 6 and 7, most decisions were relevant for diverse decision makers (federal, state, or city and county government agencies and private enterprises). However, three decisions (numbers 1 and 2 in Table 6 and number 1 in Table 7) were relevant to more interviewees than the other decisions. The first of these highly relevant decisions focuses on the need to identify which alternative water sources (e.g., desalination) will be the most cost effective in 50 years. The second highly relevant

TABLE 5. How uncertainty affects decision makers' ability to use climate information (n = 43). Note that data are missing for item 1 (n = 2), item 2 (n = 2), item 3 (n = 1), item 4 (n = 1), item 5 (n = 2), item 6 (n = 4). Chi-square tests were not conducted because some cells had less than the minimum expected count.

	Percent (%) who agree or strongly agree	
	Lower climate literacy	Higher climate literacy
1. When information is uncertain, I examine a range of plausible projections to assess the robustness of my decision.	95	100
2. I rely on most probable scenarios when making decisions under conditions of uncertainty.	78	91
3. I am accustomed to making decisions within the context of uncertain information.	84	87
4. I rely on worst case scenarios when making decisions under conditions of uncertainty.	42	65
5. When making decisions about the use of freshwater, I will only use information that has a high degree of certainty (more than 90% certain).	50	39
6. When information is uncertain, I postpone decisions about the use of freshwater.	22	5

TABLE 6. Examples of climate-sensitive decisions about the management of freshwater resources focused on optimization (O = objectives of the decision; C = choice set or management options available to achieve the objectives; S = short term, i.e., seasonal or a few years; and L = long term, i.e., 10 yr or more).

Optimization decisions (What choice produces a desired outcome?)	Time horizon	Number of interviewees indicating this decision relevant: Federal govt.	State govt.	Local govt.	Private	Example stakeholders*
1. What alternative water sources (C) will be most cost effective (O) in 50 yr (e.g., desalination)?	L	3	2	1	4	USACE; U.S. Army Garrison; U.S. Navy; DLNR; Hawaii state legislature; neighborhood boards; HECO; farmers; property developers; Kamehameha schools
2. How can we (C) meet the water needs of alternative users (O) (residential, commercial, agricultural, energy, biofuels industry, tourism, conservation, Native Hawaiian practitioners, etc.) under drier conditions in the future?	S, L	2	3	2	5	USDA Natural Resources and Conservation Service; U.S. Navy; DLNR; Hawaii Department of Agriculture; state legislature; DPP; neighborhood boards; HECO; Bishop Museum Hawaii Biological Survey; farmers; property developers; Kamehameha schools
3. Where should new power plants be built (C) to have access to adequate (fresh/ brackish/ reverse osmosis) water supply for cooling (O)?	L	1		1	1	U.S. Army Garrison; DPP; HECO
4. How can (C) we prevent disruption to the water supply used to irrigate crops (O) under future climate conditions?	L	1	1	1	2	U.S. Army Garrison; Hawaii Department of Agriculture; DPP; farmers; Kamehameha schools
5. Where should we put fences (and when should we inspect them) (C) to remove feral ungulates and control habitat altering weeds to protect the most important recharge areas (O)?	S		1		2	DLNR; Bishop Museum Hawaii Biological Survey; Kamehameha schools
6. What well distributions and pumpage rates (C) are best (O) for drier conditions in the future?	S, L	2	2		3	U.S. Army Garrison; U.S. Navy; DLNR; Hawaii Department of Agriculture; farmers; property developers; Kamehameha schools
7. What alternative energy sources (C) will be best (O) under future climate conditions?	S, L	1			3	USDA Natural Resources and Conservation Service; HECO; Kamehameha schools; farmers
8. What nonstructural options (floodplain management and flood proofing homes) and structural options (channelizing flood waters away from structures and detaining waters in safe area until flood peak subsided) (C) are most effective for projected heavy rainfall events (O)?	S, L	3	1	1	2	U.S. Army Garrison; USACE; U.S. Navy; state legislature; DPP; property developers; Kamehameha schools
9. How should we change building codes to require more pervious surfaces (C) to allow rainfall to percolate through (O)?	S, L		1	1	1	State legislature; DPP; property developers
10. What plants/animals (e.g., drought and saltwater tolerant species) (C) are best suited (O) to future climate conditions?	S, L	1	2		3	USDA Natural Resources and Conservation Service; DLNR; state legislature; farmers; property developers; Kamehameha schools
11. How can (C) water managers prevent brackish water intrusion into the potable water supply (O)?	S, L	2	1		1	USDA Natural Resources and Conservation Service; U.S. Army Garrison; Hawaii Department of Health; Kamehameha schools
12. In what areas (C) should we concentrate species conservation (O) efforts?	S, L	1	2		2	DLNR; USDA Natural Resources and Conservation Service; Bishop Museum Hawaii Biological Survey; Kamehameha schools

* USACE = Army Corps of Engineers; USDA = U.S. Department of Agriculture; DLNR = Hawaii Department of Land and Natural Resources; DPP = City and County of Honolulu Department of Planning and Permitting; and HECO = Hawaiian Electric Company.

TABLE 7. Examples of climate-sensitive decisions about the management of freshwater resources focused on evaluation (O = objectives of the decision; C = choice set or management options available to achieve the objectives; S = short term, i.e., seasonal or a few years; and L = long term, i.e., 10 yr or more).

Evaluation decisions (What outcome does a choice have)?	Time horizon	Number of interviewees indicating this decision relevant				Example stakeholders
		Federal govt.	State govt.	Local govt.	Private	
1. What is the impact on sustainable yield estimates (O) from projected demand for water (C) across all sectors (e.g., agriculture, industry, energy, ecosystems, tourism, and military) under alternative climate scenarios?	L	3	2	2	4	USACE; U.S. Army Garrison; U.S. Navy; DLNR; Hawaii Department of Agriculture; DPP; neighborhood boards; farmers; property developers; Bishop Museum Hawaii Biological Survey; Kamehameha schools
2. How should county development and watershed management plans be revised (C) to take into account (O) projected changes in rainfall, temperature, and other climate variables?	L	1	3	2	2	U.S. Navy; DLNR; state legislature; DPP; neighborhood boards; Bishop Museum Hawaii Biological Survey; Kamehameha schools
3. How much water (C) will be available in the system for human use (O) given projected changes in climate variables?	L	2	1	2	3	U.S. Army Garrison; U.S. Navy; DLNR; DPP; neighborhood boards; property developers; Kamehameha schools; Bishop Museum Hawaii Biological Survey
4. To what degree will loss of coral reefs and marine life from sedimentation (C) threaten our visitor industry (O)?	L		1		1	State legislature; farmers
5. What do increases in instream water (C) do to maintain/diminish/benefit the critical habitat for endangered species (O)?	S, L	1	2		2	USACE; DLNR; Bishop Museum Hawaii Biological Survey; Kamehameha schools

* USACE = Army Corps of Engineers; USDA = US Department of Agriculture; DLNR = Hawaii Department of Land and Natural Resources; DPP = City and County of Honolulu Department of Planning and Permitting; and HECO = Hawaiian Electric Company.

decision focuses on how to meet the water needs of alternative users (residential, commercial, agricultural, energy, biofuels industry, tourism, conservation, Native Hawaiian practitioners, etc.) under drier conditions in the future. The third highly relevant decision focuses on determining the impact on sustainable yield estimates from projected water demands across sectors under alternative climate scenarios.

Survey responses confirmed that the main climate-sensitive decision problems facing freshwater managers were related to conservation, law and policy, and infrastructure. On a four-point scale (strongly disagree, disagree, agree, and strongly agree), the main activities that survey participants ‘‘agree’’ or ‘‘strongly agree’’ with to prepare for the impacts of climate change on freshwater resources included improving watershed management (95%), increasing public education about water conservation (95%), imposing water restrictions during drought (93%), and improving policy (such as revisions or additions to existing codes, laws, and/or plans) (88%). Activities endorsed to a lesser extent included giving companies tax breaks if they use alternative sources of water such as reclaimed waste water (74%), building more reservoirs (63%), and increasing water rates so that people use less water (60%).

The survey provided additional information about decisions related to distributing freshwater resources across various sectors or stakeholders. Survey participants were asked to rank several water uses according to the priority they should be given for water supply. Mean ranks (shown in Table 8) suggest that uses with the highest priority are 1) domestic (residential and nonresidential), 2) instream flow for aquatic species, 3) agriculture, 4) traditional cultural activities (e.g., taro cultivation), and 5) freshwater flow to fishponds or estuaries.

2) WHAT ARE THE KEY DIMENSIONS OF CLIMATE-SENSITIVE DECISIONS?

The decisions described in Tables 6 and 7 differ along two main dimensions: purpose (optimization or evaluation) and time horizon (short term or long term). As shown in Table 6, decisions that tend to focus primarily on optimization are aimed at identifying a choice that will result in a desired outcome (e.g., how can we prevent

TABLE 8. SD priority for water uses to be given water supply (1 = highest priority and 10 = lowest priority).

Domestic (residential and nonresidential) (n = 39)	1.7 (1.3)
Instream flow for aquatic species (n = 39)	3.4 (2.5)
Agriculture (n = 39)	3.5 (2.0)
Traditional cultural activities (e.g., taro cultivation) (n = 39)	3.9 (2.4)
Freshwater flow to fishponds or estuaries (n = 39)	4.0 (2.2)
Recreational (e.g., fishing, swimming) (n = 39)	6.5 (2.3)
Military (n = 39)	6.5 (2.5)
Tourism (n = 39)	6.5 (2.7)
Industrial (e.g., power plants) (n = 39)	6.5 (2.5)
Urban/landscape irrigation (e.g., parks, golf courses, landscaping) (n = 38)	8.0 (2.4)

disruption to the water supply for irrigating crops in the future?). As shown in Table 7, decisions focused on evaluation are aimed at identifying the outcome of a particular choice (e.g., how should county development and watershed management plans be revised to take into account projected changes in rainfall, temperature, and other climate variables?). Both optimization and evaluation decisions are relevant across the full range of government and nongovernment participants.

The second dimension distinguishing decision problems relates to their time horizon. Most decisions reflect long-term problems (10 yr or more) and are typically the concern of planners and others developing large infrastructure (e.g., where to site a new power plant so that it will have access to an adequate water supply for cooling?) or watershed and ecosystem conservationists (e.g., what do increases in instream water do to maintain/diminish/benefit the critical habitat for endangered species?). Other decisions reflect additional short-term problems (seasonal or a few years) for some participants interested in conservation, energy, or food security (e.g., what plants/animals are best suited to future climate conditions?) because actions taken now could have an immediate as well as a future impact.

Many decisions in Tables 6 and 7 reflect complex information integration tasks. For instance, some decisions (e.g., in what areas should species conservation efforts be concentrated?) involve integrating uncertain information (e.g., projected rainfall amount, intensity, and geographic distribution) with more certain information (e.g., soil or vegetation type). Other decisions (what alternative energy sources will be best under future climate conditions?) involve integrating completely unknown information (energy technologies not yet conceived) with deeply uncertain information (future conditions). Another complex integration task involves tradeoffs between incommensurate variables. For instance, deciding how to meet water needs of alternative users, such as the biofuels industry and Native Hawaiian practitioners, involves weighing the cost of energy security (which can be measured quantitatively in monetary terms) against cultural values (which are expressed qualitatively in narrative terms).

c. Characteristics of the decision context

1) WHAT INFORMATION AND ANALYSES ARE NEEDED TO SUPPORT DECISION MAKERS' CLIMATE-SENSITIVE ASSESSMENTS AND DECISION-MAKING PROCESSES?

Interviews and workshop discussions provided new insights about the type of information and analyses needed to support decisions about how to prepare for and address the impacts of climate change on freshwater resources. For instance, there was considerable interest in how projected demand for water across all sectors (e.g., agriculture, industry, energy, ecosystems, tourism, and military) might differ under alternative climate scenarios. Individuals from agencies responsible for conservation, land management, and food security highlighted the need to disentangle the impacts of shorter-term natural/cyclical variability (e.g., El Niño–Southern Oscillation and Pacific decadal oscillation) versus longer-term climate change. In general, policy makers and planners said they are interested in receiving information about the most probable and worst case climate scenarios.

Specific information requested by most interview and workshop participants, regardless of which agencies they represent, includes projections of key climate variables such as rainfall (amount, intensity, and geographic distribution), temperature (maximum, minimum, and average), storm frequency and intensity, and sea level rise. Most participants are also interested in streamflow changes, water supply forecasts, and assessments of where the most important recharge areas are located. Data with fine resolution (e.g., 10-m grid) are in high demand by conservationists and farmers to address the complex topography of the Hawaiian Islands. Regarding specific information needs, planners and policy makers highlight the value of visualizations of impacts and vulnerabilities and specific recommendations for legislation (e.g., about adaptation plans).

The survey provided detailed information about the importance of the geographic scale of climate information for decision making. A majority of survey participants indicate that information at an island (65%) or statewide (60%) scale is often relevant. The local scale (e.g., specific to a valley or town) and regional scale were relevant to a lesser extent (see Table 9). The type of information most useful in supporting survey participants' decisions

TABLE 9. At what geographic scale is information about climate variability and change most relevant when you make decisions (n = 43)? Note that because of missing data (n = 2 for each item), the percentages will add to less than 100.

	Never relevant (%)	Sometimes relevant (%)	Often relevant (%)
Local scale (e.g., specific to a valley or town)	12	28	56
Island scale	2	28	65
Statewide scale	5	30	60
Regional scale	9	46	40

includes location-specific vulnerability assessments and implications of climate change for runoff, pollutant loads, salinity, and water supply (see Table 10).

Survey participants were asked to indicate the relative importance of various considerations driving decisions about the management of freshwater resources via a rank-ordering task. The task asked participants to order specific considerations from 1 (highest importance) to 6 (lowest importance). Mean ranks (see Table 11) suggest that the most important considerations are the needs of affected ecosystems and climate change science.

2) WHAT ARE THE BARRIERS TO USING CLIMATE INFORMATION AND WHAT ARE THE TRUSTED SOURCES OF INFORMATION ABOUT IMPACTS OF CLIMATE VARIABILITY AND CHANGE?

Survey participants were asked to indicate their agreement on a four-point scale (strongly disagree, disagree, agree, and strongly agree) with each of several reasons for not using available climate information (see Table 12). The highest percentage of survey participants agreed or strongly agreed that they do not use available climate information because of insufficient staff time to locate relevant information and no clear legal mandate requiring the use of climate information. Other reasons include a lack of technical assistance to locate relevant information and a lack of expertise to know how to use the information. The reasons with which a low percentage of survey participants agreed or strongly agreed include the uncertainty of climate science and opposition from stakeholder groups.

TABLE 11. SD importance of considerations driving decisions about the management of freshwater resources (1 = most important and 6 = least important).

Needs of affected ecosystems (n = 38)	2.3 (1.3)
Climate change science (n = 38)	2.7 (1.7)
Traditional cultural needs (n = 38)	3.3 (1.5)
Legal guidelines, laws, policies, and codes (n = 38)	3.3 (1.7)
Planning/development needs (n = 38)	3.5 (1.9)
Other economic pressures or constraints (n = 33)	4.0 (1.9)

Most survey participants (≥55%) indicated on a four-point scale that they do "not at all" rely on available national reports (e.g., the U.S. Global Change Research Program's *Global Climate Change Impacts in the United States* or *Synthesis and Assessment Products*; the National Research Council of the National Academies' *America's Climate Choices)* to aid their decisions about how to respond to the impacts of a changing climate. The Intergovernmental Panel on Climate Change's Assessment Reports are more likely to be relied on "a little" (16%), "a moderate amount" (19%), or "a lot" (21%). Most participants indicated little reliance on available websites [e.g., U.S. Global Change Research Program's www.globalchange.gov; the National Oceanic and Atmospheric Administration (NOAA)'s National Climate Data Center's www.ncdc.noaa.gov] to aid their decisions about how to respond to climate impacts.

TABLE 10. What type of information would be useful in supporting the decisions you or your agency/organization makes (n = 43)? Note that because of missing data (n = 3 for first item, n = 2 for all other items), the percentages will add to less than 100.

	Not at all useful (%)	A little useful (%)	Moderately useful (%)	Very useful (%)	Do not know (%)
Location-specific vulnerability assessment (i.e., assessing the water resources and water users' exposure, sensitivity, and capacity to adapt to climate change)	0	0	12	81	0
Implications of climate change for runoff, pollutant loads, salinity, and water supply	2	2	16	74	0
Location-specific climate change predictions (temperature, precipitation, etc.) for the medium or long term (more than 10 years in the future)	0	2	29	66	2
Location-specific climate change projections (temperature, precipitation, etc.) for the short term (from now to 10 years in the future)	0	0	30	63	2
Seasonal forecasts	0	12	23	60	0
More reliable forecasting of El Niño events and any changes in the frequency or severity of such events under climate change	0	5	33	58	0
Cost projections of water rates in various climate scenarios	2	19	21	51	2

TABLE 12. Reasons why people do not use available climate information ($n = 43$). Note that because of missing data ($n = 1$ for all items, except items 1, 4, 8, and 9 where $n = 2$), the percentages will add to less than 100.

	Strongly disagree (%)	Disagree (%)	Agree (%)	Strongly agree (%)
1. We have insufficient staff time to locate relevant climate information.	9	30	46	12
2. There is no clear legal mandate requiring me to use climate information.	12	26	53	5
3. There is a lack of technical assistance from government to help me access climate information.	9	44	39	5
4. There is insufficient expertise within my agency or organization to know how to use climate information.	12	42	39	2
5. Within my agency or organization there is a lack of perceived importance of climate information.	23	44	28	2
6. I am unable to find relevant climate information.	7	63	26	2
7. I do not know what climate information I need.	14	58	26	0
8. Available climate information is not relevant to decisions and planning that occur within my agency or organization.	35	39	16	5
9. I worry about opposition from stakeholder groups.	21	56	14	5
10. Climate science is too uncertain to be used in real world decision making.	30	51	12	5

The survey also showed that regardless of climate literacy level, the most trusted sources of information about climate impacts on freshwater resources include the University of Hawaii, scientific journals, the U.S. Geological Survey (USGS), and NOAA. Compared with people with higher climate literacy, those with lower climate literacy tend to be more trusting of information from agricultural extension agents, the National Weather Service, the Hawaii Water Resources Protection Plan, television weather reporters, and family and friends (see Table 13).

d. Workshop evaluation

Finally, workshop evaluation forms were completed by 26 people. Most participants rated the workshops as "extremely useful" (61%) and "extremely relevant" (65%). Most participants indicated that the workshops helped to improve their understanding of the impacts of climate change on water resources in Hawaii (81%) and their ability to connect climate change to their job (69%). Open-ended comments provided suggestions for improving the workshops, including extending the overall time to allow more discussion of specific topics, such as how to connect climate science to decision makers.

4. Discussion

The management of freshwater resources on Pacific islands is increasingly challenging in the face of climate change. Despite a lack of precise climate projections, government agencies and other organizations need to assess, predict, and distribute water resources. To improve our understanding of how to connect climate information with decision makers' needs, we used qualitative and quantitative methods to systematically characterize relevant aspects of freshwater managers in Hawaii, their climate-sensitive decisions, and the contexts in which they are making decisions. The PTF and DUST frameworks guided our investigation of the nature of different decisions and features of individuals and contexts that might lead to better or worse decisions. In the discussion below, we highlight implications of the findings under these frameworks for improving support for decisions about freshwater resource management under conditions of uncertainty.

a. Characteristics of decision makers

The first category of variables that affects decisions under conditions of uncertainty relates to the decision maker. Specifically, our first research question asks what are decision makers' perceptions of and concerns about climate change impacts, especially related to the management of freshwater resources? The results of the present study indicate that the people responsible for managing freshwater resources in Hawaii perceive climate change as posing a worrisome risk with dangerous impacts on freshwater resources. Most participants in this study expect less water will be available. The high level of concern indicates that deliberations around water and climate change are likely to focus on what can be done to attenuate the relevant risks (as opposed to whether or not there is a risk to address). The concern also suggests that the water managers are likely to be receptive to climate information that helps to improve their decision making.

Our second research question asks what capacity decision makers have to use climate information to support

TABLE 13. How much do you trust sources of information about the impacts of climate change on freshwater resources ($n = 43$)? Note that missing data include $n = 2$ for item 6; $n = 4$ for items 7, 9, 11, 14, 15, 17–20, 23, and 24; $n = 5$ for item 21; and $n = 3$ for all other items. Chi-square tests were not conducted because some cells had less than the minimum expected count.

	Percent (%) who find the source moderately or highly trustworthy			
	Lower climate literacy		Higher climate literacy	
	(%)	Rank	(%)	Rank
1. University of Hawaii	82	3	100	1
2. Scientific journals	71	5	100	1
3. U.S. Geological Survey	88	2	96	3
4. National Oceanic and Atmospheric Administration	82	3	87	4
5. Professional listservs, conferences, and workshops	59	9	78	5
6. National Weather Service	89	1	78	5
7. City and county of Honolulu Board of Water Supply	69	7	70	7
8. State climatologist	71	5	65	8
9. Pacific RISA	44	14	65	8
10. State of Hawaii Commission on Water Resource Management (CWRM)	65	8	56	10
11. Center for Island Climate Adaptation Policy and Planning (ICAP)	31	20	56	10
12. Pacific ENSO Applications Climate Center	53	11	52	12
13. Nonprofit environmental organizations	41	16	43	13
14. Pacific Climate Information System (PaCIS)	25	21	43	13
15. Newsletters and bulletins	50	12	43	13
16. Agricultural extension agents	47	13	35	16
17. Radio	38	18	35	16
18. Hawaii Water Resource Protection Plan	56	10	30	18
19. Television weather reporters	44	14	17	19
20. Family and friends	37	19	17	19
21. Office of Hawaiian Affairs	20	11	17	19
22. Private corporations	41	16	9	22
23. State Department of Hawaiian Home Lands	13	23	4	23
24. Social media (Twitter, Facebook, etc.)	6	24	0	24

their adaptation decisions? We found that freshwater managers are, on average, highly educated and experienced in diverse professions related to environmental management, suggesting that they are knowledgeable about island hydrology and factors affecting its sustainability. As would be expected, the survey showed that participants have a high level of climate literacy. Nonetheless, a worrisome proportion of respondents revealed incorrect beliefs about the state of scientific consensus about climate change and the major causes of climate change. In addition, although about half of the participants report feeling fairly well informed about the likelihood and consequences of climate change impacts on freshwater resources, about half of the participants report that they do not feel well informed about how to prepare for the impacts. These findings suggest island water managers have a good capacity to understand and prepare for the implications of climate projections for aquifer recharge and streamflow, but some knowledge gaps still need to be addressed and some additional information needs to be provided about the effectiveness of alternative adaptation strategies for maintaining quality water supplies. Emphasis should be placed on improving decision makers' understanding of the implications of alternative climate scenarios and how to use uncertain climate information. This might include training on how to utilize traditional water resource planning techniques or new techniques, with new assumptions about future climate.

An interesting finding is that respondents with lower climate literacy seem to be more trusting of climate information from familiar or personable sources. This pattern of results is consistent with previous research showing that in the absence of sufficient knowledge to inform decisions under conditions of uncertainty, people tend to rely on trusted others for support (Siegrist 2000). This finding suggests that it is important for the providers of climate information (e.g., USGS and University of Hawaii) to continue building familiarity with end users of information so that legitimate and useful training can be provided by credible institutions to those who need it.

b. *Characteristics of decision problems*

The second category of variables under the PTF and DUST frameworks that affects decisions under conditions of uncertainty relates to the decision problems.

Our third research question asks what are the climate-sensitive decisions that decision makers are currently facing or likely to be facing in the future related to freshwater resources? The present study reveals that freshwater managers in Hawaii make a wide range of climate-sensitive decisions related to conservation, law and policy, and infrastructure. Key decisions include identifying cost-effective water sources for the future, meeting the needs of alternative users under drier conditions, and determining the impact on sustainable yield estimates from projected water demands under alternative climate scenarios. However, specific interests about climate change impacts on freshwater vary with the nature of participants' professional responsibilities. Heavy rainfall is most relevant to those responsible for disaster risk reduction; droughts and floods are most relevant to those responsible for community planning infrastructure development, conservation, and food security. Clearly, the climate variables needed to address the management issues facing different agencies and organizations will vary with their missions. Similarly, the spatial and temporal resolution of the information of most relevance will depend on the decision problem being addressed (e.g., is the information required to help identify choices, mobilize resources, or monitor conditions?)

Our fourth research question asks what are the key dimensions of climate-sensitive decisions? The present study found that the decisions facing freshwater managers pose complex problems characterized along several dimensions as described by Moser (2012). One dimension reflects the optimizing versus evaluative nature of the decisions. Most decisions focus on optimization, identifying strategies to produce desired outcomes (e.g., how to supply adequate water to diverse users under drier conditions in coming decades?). Some decisions are evaluative, however, emphasizing the need to examine the outcomes of given strategies (e.g., how will development be affected by alternative responses to drier conditions?). Decisions identified in this study reflect both short-term and long-term time horizons and typically afford opportunities to learn from updated information. The decisions require the integration of information with different levels of uncertainty and different types of attributes (quantitative versus qualitative). These results imply that information providers need to clarify with water managers which type of decision the information will be used for, whether the research scale matches the decision-making time scale, the possibility of integrating new information into the management process, and whether the climate output and other relevant information can feed into existing models and procedures.

c. *Characteristics of the decision context*

The third category of variables under the PTF and DUST frameworks that affects decisions under conditions of uncertainty relates to the decision context. Our fifth research question asks what information and analyses are needed to support decision makers' climate-sensitive assessments and decision processes? The results of this study suggest that the climate information most useful for decision makers includes vulnerability assessments incorporating projections about temperature, rainfall distribution, storms, sea level rise, and streamflow changes. Decision makers are particularly interested in the most probable and worst case climate scenarios and their implications for specific issues such as runoff, pollutant loads, salinity, and water supply. Information is most relevant when it is at an island or statewide scale. Individuals responsible for conservation, land management, and food security are more interested than others in understanding the impacts of shorter-term climate variability versus longer-term climate change. These results provide clear directives to information providers about what existing information is useful and what new information needs to be generated.

Our sixth research question asks what are the barriers to using climate information and what are the trusted sources of information about climate variability and change? The present study found that the main barriers to using available climate information include insufficient staff time or expertise and the lack of a clear legal mandate. Reports and websites with climate information were not typically utilized to assist decisions about responding to climate change. Finally, the survey results showed that credible institutions (University of Hawaii, scientific journals, the USGS, and NOAA) were the most trusted sources of information about climate impacts on freshwater resources. These results suggest that simply making climate information available is insufficient to improving decision making. Additional efforts are needed to train potential users in where and how to access the information and, importantly, in how it can be used in their decision processes. Legal analyses (e.g., Wallsgrove and Penn 2012) may help to show how existing and proposed laws and policies can best support the use of climate information. Partnering with credible institutions in these efforts will increase the rapid uptake of the most recent climate information.

d. *Limitations*

Several limitations of this paper raise important questions. First, do the results generalize to other samples of freshwater decision makers? This sample was drawn from stakeholders making decisions about one watershed in the state of Hawaii and may not represent decision makers working on watersheds on other islands or elsewhere in the United States. Confidence that the findings will be relevant in other settings is drawn from the fact that a substantial subset of the participants works on multiple watersheds or has statewide responsibilities. Although focusing on a specific watershed provided the opportunity to ensure that this study's findings will be applicable to real world decision problems, further exploration of the variance across decision makers in diverse settings will provide important information about how to make climate science useful to a wider range of decision makers.

Another important caveat concerns the small sample size of this study. It is possible that more information would have been obtained through more interviews with a broader sample of individuals representing more diverse backgrounds or with a more in-depth focus on a specific sector (e.g., agricultural decision makers may have raised more short-term single-opportunity decision problems). Within this sample, however, the questions posed in the qualitative work were thoroughly addressed because little new information was obtained by the end of the second workshop. This phenomenon, called saturation, is an indication that a topic has been adequately sampled (i.e., enough interviews conducted or enough text analyzed; Glaser and Strauss 1967). Nonetheless, a larger sample would permit investigation of whether the results (e.g., about decisions, perceptions, and needs) differ depending on participants and the scale of the agency at which they work. In addition, research should examine whether the present findings generalize to individuals with different expertise or professional responsibilities.

e. Conclusions

The results summarized above are consistent with previous reports suggesting that linking science to policymaking and management practice is a difficult challenge (Pielke 2007). The timing and extent to which climate information matters to decision makers concerned with adaptation depend on the concerns, preferences, and skills of individual decision makers, key dimensions of the decision problem, the relevance of climate information, and barriers to and support for information usage. Consistent with the PTF and DUST frameworks, the descriptive work in this study shifts the focus to the decision maker and the decision-making process to determine where and when climate science is important. Ultimately, an integrative approach will be needed so that climate science is tailored to the needs of particular decision makers, in some cases to help understand and define problems and possible response strategies and in other cases to assist with monitoring and evaluation. Calls for more information distinguishing the impacts of climate variability versus climate change, high-resolution projections of key climate variables, and location-specific vulnerability assessments will be best addressed by interdisciplinary teams of researchers that understand the needs of specific decision makers. We also need to determine what type or amount of uncertainty analysis is needed for which type of decision maker or decision and how uncertainty is best communicated. A fine-grained analysis by agency type was beyond the scope of this study, but a more detailed analysis with a larger sample is warranted. Moreover, while determining where and when uncertainty matters is important, the larger set of organizational variables (by agency) that affect the decision-making context also need to be addressed (Finucane 2009). In short, understanding how climate science can support adaptation decision making is an important element of bridging the gap between science and decision making.

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